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A. Hallihan

The Development of a Practical Framework
for the Implementation of JIT Manufacturing

Supervisors: P. Sackett and G. Williams

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Abstract

This research develops a framework to guide practitioners through the process of implementing Just In Time manufacturing in the commercial aircraft manufacturing industry. The scope of Just In Time manufacturing is determined through an analysis of its evolution and current use. Current approaches to its implementation are reviewed and shortcomings are identified. A requirement to allow practitioners to tailor the approach to the implementation of Just In Time manufacturing, according to the context of the particular manufacturing system, is endorsed.

Three case studies of Just In Time manufacturing implementation within the commercial aircraft manufacturing industry, conducted as part of this research, are presented and analysed. The benefits of Just In Time manufacturing implementation in the cases are shown to be signficant and immediately apparent.

Two key factors in the implementation of Just In Time manufacturing are identified. These are the concepts of perceived opportunity for improvement and distributed support for implementation. These concepts are supported by other researchers. They form the basis of the practical framework to guide the implementation of Just In Time manufacturing.

The framework combines the concepts with existing research in the areas of: strategy formulation; performance measure selection; target setting; the nominal group technique; and, literature on the techniques of Just In Time manufacturing. The framework provides a novel and reliable mechanism that allows a practitioner to identify which of many potential approaches towards Just In Time manufacturing should be taken. This is achieved using the detailed mechanisms presented in the framework to evaluate the perceived opportunity and distributed support.

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Declaration - use of material

The author has published the following work:

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Chapter One

Thesis Context

1.0 Introduction

This chapter sets the context of the research by introducing just in time (JIT) manufacturing and approaches for its implementation. It introduces the commercial aircraft manufacturing industry, which was the main test domain of this research. It identifies the need for a practical method to guide the implementation of Just In Time manufacturing. The design of the research programme is presented. The academic contribution and industrial significance of the research are highlighted, and the structure of the thesis is summarised.

Definitions and descriptions are provided to identify what is meant by the following key terms: commercial aircraft manufacturing industry; JIT manufacturing; and, the implementation of JIT manufacturing.

1.1 Just In Time (JIT) Manufacturing

There is a range of definitions of JIT manufacturing proposed in the literature (Keller and Kazazi 1993). This has produced confusion about the exact nature of JIT manufacturing. Alternatives include: a manufacturing philosophy; a purchasing system; an inventory control system; a shopfloor control system; and a set of techniques. An analysis of the evolution, and current use, of JIT manufacturing in chapter two will demonstrate that JIT manufacturing:

- is a form of manufacturing management which pursues a philosophy of improvement through the continuous elimination of waste;
- is realised through modification of the manufacturing system using a diverse and wide reaching set of waste elimination techniques to reduce the seven wastes of motion, waiting time, overproduction, processing time, rejects, inventory, and transport;
- can benefit from the involvement of, and affect, a wide span of manufacturing stages including design, supply, production, distribution, and sales and marketing; and
- can benefit from the involvement of, and affect, a wide span of manufacturing support functions including personnel, quality systems, engineering, accounting, and facility maintenance.

Manufacturing systems pursuing JIT manufacturing can operate with lower levels of inventory than traditional batch and mass production systems, and produce goods in a shorter leadtime. JIT places emphasis on the availability of workcentre capacity and labour flexibility (Oliver 1991), instead of using large buffers of inventory distributed throughout the manufacturing system. Short leadtime improves the ability of the manufacturing system to respond to customer orders, and has greater product flexibility, as defined by Browne et al (1984). JIT manufacturing requires many changes to be made to traditional systems to allow successful operation with reduced buffers of inventory and batch sizes. Benefits include improved product quality, reduced leadtime, increased productivity, reduced cost, and increased flexibility.

Cusumano (1988), Ohno (1988a; 1988b), Shingo (1989), and Womack, Jones and Roos (1990) have presented commentaries on the development of the JIT manufacturing system in the post-war Japanese automotive industry. They described many of the waste elimination techniques involved in JIT manufacturing, which are well documented by a large number of authors, including Monden (1983; 1994), Schonberger (1982a; 1986), Dyer (1987), Suzaki (1987), Hay (1988), and Harrison (1992). There are a growing number of cases and surveys of JIT usage which cover individual companies (Hall 1982; Lippa 1986), specific functions within a company (Benson 1986; Billesbach, and Schneiderjans 1989), specific industrial sectors (Celley, et al 1986; Cheng 1988; Hallihan, Williams, and Sackett 1995) including non-manufacturing environments (Giunipero, and Keiser, 1987; and Inman, and Mehra, 1991), comparisons within a specific national economy (Voss, and Robinson 1987; Im, and Lee 1989), comparisons between national economies

(Billesbach, Harrison, and Croom-Morgan 1991) and the world economy (Womack, Jones, and Roos 1990). These identify that from the Japanese automotive industry JIT manufacturing is being introduced and spread throughout industries with increasingly lower production volumes and higher variety, such as the commercial aircraft manufacturing industry.

1.2 The Commercial Aircraft Manufacturing Industry

The commercial aircraft manufacturing industry is large. The ten largest commercial aircraft manufacturers achieved sales of US$41,323M during 1993 (O'Toole 1994b). A recent survey presented it as a mature global industry with competition based on cost, quality, and rapid response times, and little differences from nation to nation (Ingersoll Engineers 1994: 6-7).

From 1992 to 1995, the commercial aircraft manufacturing industry has faced increasing pressure because of overcapacity across many manufacturers. The air transport industry suffered from reduced growth of business volume, specifically since the Gulf War of 1991 to 1992. This has resulted in a fall in demand for commercial aircraft as commercial airlines reevaluate their capital investment and capacity development programmes. Many commercial aircraft manufacturers have reduced their rate of production several times.

The level of overcapacity is increased by the reduced level of worldwide defence spending since the demise of the Cold War. Demand has reduced in the military aircraft manufacturing industry, many of whose members are also present in the commercial aircraft manufacturing industry. These include Aerospatiale, Boeing, British Aerospace (BAe), Daimler Benz Aerospace, McDonnell Douglas, and Saab-Scania. Potential entry of new manufacturers into the commercial aircraft manufacturing industry, principally from the Pacific Rim, have threatened to further increase the level of overcapacity. Companies established in the industry have increased the barriers to entry by reducing product cost. Barriers to entry are further increased by the reduced size of the commercial aircraft market as the likelihood of achieving sales to recoup product development costs and attain profitability is reduced. Some new entrants have reached the market (eg. IPTN of Indonesia with the N250 regional turboprop aircraft). However, due to the increased barriers to entry, new entrants are finding support for new projects increasingly difficult to secure (eg. Japan Aircraft Development Corporation and Boeing with the YS-X/NSA, and Korea and China with a similar 100 seat aircraft, Lewis 1995).

An anticipated reaction to the overcapacity problem is a series of mergers of many smaller manufacturers into fewer larger companies, which then rationalise production capacity. This has been demonstrated by the agreement regarding regional jets and regional turboprops between Avions de Transport Regional (ATR), of Alenia and Aerospatiale, and Jetstream Aircraft and Avro International Aerospace, of BAe (O'Toole 1995b). The policy of the established companies is influenced by the desire to secure powerful positions from which to negotiate their merging with others.

Competitive pressures are driving the interest in the mechanisms and benefits of JIT manufacturing. Some companies have been shown to be active in the introduction of elements of JIT manufacturing:

- Avro's reductions in final assembly leadtimes from 22 weeks in 1993 to nine weeks in 1994 through lean manufacturing cells (Cook 1994);
- Fokker's reduction of assembly leadtimes from 120 to 55 days (O'Toole 1995b);
- the introduction of first tier supply requirements by Boeing incorporating many elements of JIT manufacturing and representing an investment of one thousand man-years in its development (Williams, et al 1994);
- Short Brothers' reductions of machined parts leadtimes from sixteen weeks to ten days (O'Toole 1994a); and,
- Bombardier's three-fold increase in revenues since 1990 with negligible increases in manpower, floorspace reduction of 35%, and leadtime reductions from 165 days to 50 (Warwick 1995);

Further demonstrations of interest in JIT manufacturing can be found within the commercial aircraft manufacturing industry, including:

- the importance of the use of the Kawasaki Production System (KPS) as a form of JIT manufacturing stressed in the 1993 BAe Annual Report;
- Boeing's recent pledge to reduce aircraft leadtimes to between six and eight months by the elimination of wasteful activities (Wilson 1994);
- Airbus Industrie's pledge to reduce narrowbody aircraft leadtimes from seventeen months at March 1994, to nine months at January 1996, and then on to six months after this (BAe Airbus News, 1994);
- Fokker's plans for reducing production leadtime to nine months, (O'Toole

1995b);

- concern about Japanese competition extending to aerospace industries (Cheng, and Musaphir 1993);
- the "Competitiveness Challenge" issued by the Society of British Aerospace Companies which seeks to achieve a reduction of manufacturing leadtimes of 50%; and
- the Innovative Manufacturing Initiative research objectives, identified by the UK aerospace industry and supported by the Engineering and Physical Sciences Research Council, which incorporate many elements of JIT manufacturing (Innovative Manufacturing Newsletter 1994).

Interest in the implementation of JIT manufacturing in the commercial aircraft manufacturing industry raises the question of: "How should JIT manufacturing be implemented?"

1.3 The Implementation Of JIT Manufacturing

Ramarapu, Mehra, and Frolick (1995) concluded that there is a lack of consensus concerning the interpretation and meaning of JIT implementation. For the purposes of this thesis, the process of JIT implementation is the combination of more than one element of JIT manufacturing in concert to eliminate the seven wastes from the manufacturing system. Used on its own, a solitary element does not constitute a JIT implementation. The process of JIT implementation starts when the first elements are used in concert with the purpose of waste elimination. A JIT implementation continually matures as additional elements are employed, or their use extended. Implementation itself, does not have an end point, but continues to mature. This description of JIT implementation is developed and supported in chapters two and three.

Im (1989) in a survey of the JIT literature between 1971 and 1986 concluded that the emphasis is moving towards how JIT can be implemented successfully. In another survey of literature between 1977 and 1990 Moras, Jalali, and Dudek (1991) showed that the number of articles discussing implementation of JIT manufacturing was increasing. Yasin and Wafa (1996) supported this, stating that the question is no longer whether JIT manufacturing works, but how to make it work. Approaches to JIT implementation proposed in literature are presented, codified, and discussed in chapter three. However, after reviewing over 400 references Keller, and Kazazi (1993) concluded that "there is no general consensus among practitioners and researchers regarding a particular recommended route to JIT implementation". Another finding of Im (1989) was that although cases in literature give some hints and clues, they do not provide an explicit model to follow. Many companies have implemented their JIT manufacturing through a trial and error approach. High levels of dissatisfaction with how JIT has been implemented have been identified (Billesbach, Harrison, and Croom-Morgan 1991). A concern raised by Shingo (1989: xxii-xxiii) was that although books outline principles and techniques of JIT manufacturing in detail, the treatment is specific and anecdotal, and there is no discussion of what has to be done to achieve JIT. Fielder, Galletly, and Bicheno (1993) concluded that JIT is a large set of techniques which cannot all be implemented at once, and that there is a gap in detailed practical advice available for managers who would like to implement JIT.

Understanding the underlying principles of JIT manufacturing is important in its implementation (Harber, et al 1990). Superficial implementation of JIT waste elimination techniques will not sustain a long term commitment to continual improvement.

1.4 Problem Statement

JIT manufacturing is widely presented as providing significant benefits, but there is no clear consensus regarding the exact nature of JIT manufacturing, or approaches for its implementation. Many implementations to date have followed a trial and error approach. Researchers have studied JIT manufacturing and developed models to describe its implementation. To achieve the potential benefits of JIT manufacturing, practitioners require practical and detailed guidance. Current implementation models do not provide such guidance. The absence of a practical and detailed model to follow is an issue of concern to those interested in the pursuit of JIT manufacturing.

To allow practitioners to achieve the full benefits of JIT manufacturing this research is required:

- to structure the approach taken to implementation such that companies can proceed through JIT manufacturing in a controlled manner;

- to guide the use of the techniques of JIT manufacturing and the associated literature explaining the techniques;
- to provide understanding of the underlying principles of JIT manufacturing and its implementation; and,
- to encourage multifunctional participation in the process of implementation, to ensure that the wide ranging nature of the changes involved in JIT implementation are adequately addressed.

1.5 Research Objectives

The aim of this research is to develop a practical framework to support practitioners throughout the implementation of JIT manufacturing in the commercial aircraft manufacturing industry. The framework should enable practitioners to determine an implementation plan that specifies which techniques of JIT manufacturing should be applied, where in the manufacturing system, and when.

To achieve this research aim, the following objectives were identified:

- to review literature covering the evolution, current use, and definition of JIT manufacturing;
- to review, classify, and evaluate approaches to the implementation of JIT manufacturing presented in literature,
- to study implementations of JIT manufacturing in the commercial aircraft manufacturing industry;
- to identify factors that determine the approach taken to JIT implementation and their interrelationships;
- to identify methods to reliably evaluate the presence of such factors in a practical environment, and;
- to integrate these factors with exiting research to develop a coherent and practical framework to support practitioners throughout the implementation of JIT manufacturing.

1.6 Design Of The Research Programme

The nature of the problem statement and research objective are complex. They suggest a requirement for a practical focus in the research programme, and this leads to difficulties regarding scientific replication. This presents a need to carefully consider the approach taken. Several different approaches may be taken to the investigation into the research objectives, above. After discussing the relative advantages of experiments, surveys, archival analysis, historical analysis, and case studies, Yin (1994: 9) concludes that:

> "we can identify some situations in which all research strategies might be relevant (such as exploratory research), and other situations in which two strategies might be considered equally attractive. We can also use more than one strategy in any given study (for example, a survey within a case study or a case study within a survey). To this extent, the various strategies are not mutually exclusive. But we can also identify some situations in which a specific strategy has a distinct advantage. For the case study, this is when a 'how' or 'why' question is being asked about a contemporary set of events over which the investigator has little or no control".

A case study approach was selected for this research. This was to investigate how and why JIT manufacturing is implemented, in real contemporary manufacturing systems over which the researcher would have little or no direct, precise, or systematic control. Evidence from multiple cases is often considered to be more compelling, and the overall study more robust (Herriot and Firestone, 1983). For these reasons, an opportunity to conduct a multiple case study was sought and secured with the consent of the General Manager of the British Aerospace Chadderton factory.

Important elements of the research design for a case study approach include:

- the study's questions. These clarify the nature of the research and, as shown above, are preceded with "how" and "why". For this research design, the study questions are how and why manufacturers implement JIT manufacturing;
- the propositions made. These direct the attention of the research towards areas that should be examined within the scope of the research. The more a study contains specific propositions, the more it will stay within feasible limits. The propositions for this research are inspired by Im (1989) who asked: is it possible to develop a globally prescriptive framework for JIT implementation; is there an ideal sequence of implementing certain JIT practices for each manufacturing process type; and, should each company pursue a level of JIT implementation selectively, adopting JIT practices based on its manufacturing process type? Developing these, the propositions for this research are:

- o establish if there is one prescriptive framework to successfully guide the process of implementing JIT manufacturing;
- o establish if there is one prescriptive framework to successfully guide the process of implementing JIT manufacturing for an industry sector, such as the commercial aircraft manufacturing industry; and,
- o establish if each company should pursue a level of JIT implementation selectively, adopting JIT practices based on its particular circumstances.

Further propositions developed from the objectives are:

- o establish which issues affect the implementation of JIT manufacturing; and,
- o establish how implementation issues can combine to influence the implementation of JIT manufacturing.

- the unit(s) of analysis. The immediate topic of the case study should be distinguished from the context of the case study. Specific time boundaries are needed to define the beginning and the end of the case. It is useful to select units of analysis that are consistent with that of other cases in literature, to allow analysis of these cases with the current research. The unit of analysis for this research is the set of activities, including decision making, associated with the implementation of JIT manufacturing in a defined manufacturing system. This is set in the context of the physical and human boundary of a specified manufacturing system, such as a manufacturing cell, and are investigated over the duration of thirteen months.

To demonstrate construct validity a research design should identify specific types of change that are to be studied, and select appropriate measures to demonstrate the degree of change. For this research:

- the use or otherwise of specific JIT manufacturing waste elimination techniques, identified in chapter two, were studied. Direct observation of implementation activities and of implementation plans constructed by the management of the manufacturing systems was used to determine the degree to which each waste elimination technique was employed;
- the presence or otherwise of a range of implementation issues, such as those identified in chapter four, were studied. This was the most difficult to operationalise, and required considerable collection of information through direct observation and interviews with a large number of different groups of people associated with the relevant manufacturing system;
- performance of the manufacturing systems according to five performance

measures, identified in chapter five, were studied. This was necessary to determine the effect of JIT manufacturing on the manufacturing systems, and the measures selected were consistent with the literature regarding JIT manufacturing. They were setup time reduction, batch size reduction, work in progress reduction, leadtime reduction, and labour productivity improvement.

Two methods to increase construct validity are:

- the use of multiple sources of evidence which converge. In this research, these included published literature, direct observation, company documentation and reports (including annual reports), and interviews with people at the case site. Each of these were repeated over the three case studies; and
- the review of a draft case study report by key informants. A publication presenting the three case studies was reviewed by the managers and engineers of each of the manufacturing systems affected.

Internal validity is required by explanatory case studies which seek to determine whether event X led to event Y. The main point to establish is that all of the evidence, from multiple sources, is convergent. In this research, the multiple sources of evidence listed above are shown later to converge. This demonstrates theoretical replication of the concepts identified, and is further reinforced by convergence with other cases drawn from literature.

External validity is required to allow generalisation beyond the immediate cases. The extent to which the results of the research can be generalised is determined by the level of external validity of the research design and results. To establish external validity, a theory should be tested in multiple cases with replications in a second and even a third case. Once this has been achieved, the results may be accepted for a much larger number of similar cases (Yin 1994: 35-36). In this research, a degree of external validity has been established through the replications across three cases.

A literature review was undertaken at the start of this research, and maintained throughout the duration of its course. This made use of the facilities of the Cranfield University library, including CD-ROM databases such as Compendex and Inspec, the Bath Information and Data Service (BIDS), the Recent Advances in Manufacturing (RAM) database compiled by the University of Nottingham, and on-line searches of international databases, including NASA and the European Space

Agency. The British Library Service was also accessed, via the Cranfield Library. Subject areas of interest included:

- identifying, modelling, and defining JIT manufacturing;
- the origins and recent use of JIT manufacturing, along with the mechanisms which drove the expansion of its use;
- the impact of JIT manufacturing on industries and economies;
- issues that affect the implementation of JIT manufacturing;
- approaches to, and recommendations for, the process of implementing JIT manufacturing;
- methods for the formulation of business and manufacturing strategy;
- the selection of performance measures and setting of targets;
- detailed guidance for the use of individual waste elimination techniques within JIT manufacturing; and
- the commercial aircraft manufacturing industry.

The literature survey led to the identification of the propositions, above.

Via the British Aerospace Cranfield Manufacturing Centre and with the agreement of the General Manager of British Aerospace Chadderton, the researcher later participated in three implementations of JIT manufacturing within the commercial aircraft manufacturing industry, reported in detail in the thesis. Over the course of around one year, this involved full time participation in the preparation, information collection, analysis, decision taking, and implementation activities for all cases. General access was also secured to five other UK sites going through similar changes.

The research followed the methods of action research. The term "action research" was introduced by Kurt Lewin in 1946 to denote an approach which combined generation of theory with changing the social system through the researcher acting on or in the social system. The act is presented as the means of changing the system and generating critical knowledge about it. (Susman and Evered 1978)

Rapoport (1970) wrote that "action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable framework". Susman and Evered (1978) accepted this and added a third aim to "develop the self-help competencies of people facing problems".

The essence of action research studies is the introduction of planned change and the observation of its results. In action research the generality of the findings is very low. However, if the research is treated as a case study and reported in such a form that it can be discussed and evaluated along with other case studies, some generality is possible. (Cherns 1969)

According to Wilson (1979), ideally an action research programme will include the following phases:

- initial assessment of the situation. In a simple case such as an example of an intensive reading programme for pupils in a school in Liverpool initial assessment consisted of establishing the reading attainments of the pupils before the research team began their innovation.
- initiate the change - the "action" phase of the research. In the example above, members of the research team who were trained teachers began an intensive course with the pupils to improve the children's reading skills.
- evaluate the results of the "action".
- initiate further changes or "action" and move through the cycle of planned changes and evaluation again.

Lewin described action research as proceeding in a spiral of steps, each of which is composed of planning, action and the evaluation of the result of the action. In practice, the process begins with a general idea that some kind of improvement or change is desirable. Having decided on the field and made a preliminary reconnaissance, the action researcher decides on a general plan of action. The first action step is a change in strategy which aims not only at improvement, but at a greater understanding about what will be possible to achieve later as well. The action researcher devises a method of monitoring the effects of the first action step, the circumstances in which it occurs, and what the strategy begins to look like in practice. As the first step is implemented, new data starts coming in and the circumstances, action and effects can be described and evaluated. This evaluation stage amounts to a fresh reconnaissance which can prepare the way for new planning. The general plan is revised in the light of this new information and the second action step can be built on the first along with appropriate monitoring procedures. The second action step is then implemented, monitored and evaluated; and the spiral of action, monitoring, evaluation and replanning continues. (McTaggart 1982)

The activities of the research programme are shown to incorporate these steps, Figure 1.1.

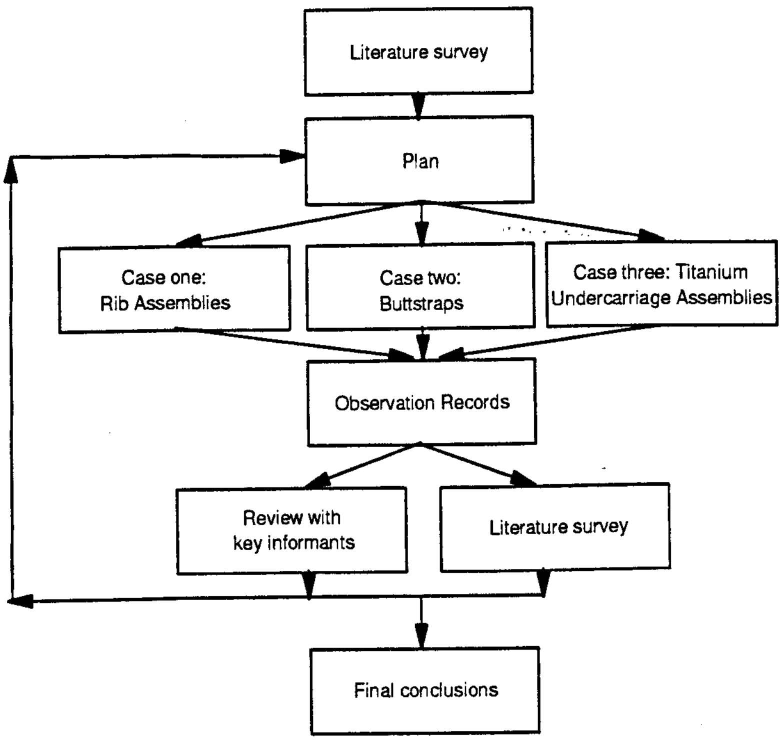

Figure 1.1: Research programme

1.7 Academic Contribution Of The Research

The key novelties of this research are:

- the identification of a practical method which allows managers to identify approaches to the implementation of JIT manufacturing that are tailored to their individual circumstances;
- the identification of two key factors that affect the process of JIT implementation, together with practical methods for their evaluation;
- understanding of how the two key factors combine to influence the process of JIT implementation; and,
- the integration of the above with existing research to provide a coherent framework that provides guidance for the implementation of JIT manufacturing.

1.8 Industrial Significance Of The Research

Existing frameworks are presented and evaluated in chapter three, and shown to exhibit a number of shortcomings in their ability to direct the successful implementation of JIT manufacturing. The practical framework developed overcomes these shortcomings. This results in increased reliability in the process of JIT implementation, and therefore improves the likelihood of achieving the accepted benefits of JIT manufacturing.

The likely economic consequences of JIT implementation, and hence the potential of this research, are demonstrated in chapter four, "The Chadderton Industrial Cases", as significant and immediately apparent. In the three case studies the cost of WIP was reduced by over £0.5M or 46%, leadtimes were reduced by between 36% and 72% and on average by 51%, and average productivity increased by 23% all within a period of five months. Due to the continuous improvement of the manufacturing system throughout JIT implementation, these benefits would be expected to increase with time.

1.9 Thesis Structure

Chapter one has introduced the subject area and identified the problem domain of JIT implementation, the research objectives, design, and deliverables. The academic contribution and industrial significance of the research were highlighted.

The early use and evolution of JIT manufacturing and its current use are reviewed in chapter two. This provides an understanding of the goals and mechanisms of JIT manufacturing. A core set of waste elimination techniques that typify current use are identified. Following this, the reader is introduced to the confusion surrounding the definition of JIT manufacturing, after which a model of JIT manufacturing is developed based on analysis of the evolution and current use presented earlier. This provides a working definition for what is considered as JIT manufacturing throughout this thesis. It identifies key elements of JIT manufacturing that act as a common core by which JIT manufacturing can be identified and to which additional elements may be added as an implementation matures.

Chapter three identifies the complexity of the problem that is JIT implementation.

Existing guidance from literature is classified and reviewed. General implementation structures are rejected as being too simplistic and incapable of offering sufficient practical advice for managers. Prescriptive frameworks are demonstrated to inherently present significant risks of implementation failure, and so are rejected. Tailored frameworks offer the potential for overcoming these risks of failure. However, existing frameworks are shown to be incapable of providing a solution to the JIT implementation dilemma, identified as determining which element of JIT manufacturing should be applied, where in the manufacturing system, and when.

Three case studies demonstrating the implementation of JIT manufacturing pursued during the course of this research are presented in chapter four. Analysis of the cases identifies two key factors which are shown to determine the solution to the JIT implementation dilemma. The potential industrial significance of the research is calculated by extrapolating the case study results across the commercial aircraft manufacturing activities of British Aerospace.

Chapter five defines, explains, and justifies the two key factors identified in chapter four. They are combined with the model of JIT manufacturing, developed in chapter three, to demonstrate the basis of an approach to the successful implementation of JIT manufacturing, which is shown to be consistent with the three case studies and others drawn from literature. These are carried forward to the development of the practical framework for JIT implementation.

The model of JIT manufacturing, and the two key factors are combined in chapter six with other research to create the practical framework for JIT implementation. Existing research in the areas of strategy identification, performance measurement selection and target setting, and detailed waste elimination technique application methods are incorporated into this. Practical mechanisms to evaluate the two key factors are developed. The supporting organisation for the framework is described, along with the tasks involved throughout.

The thesis is summarised in chapter seven. Conclusions are drawn against each of the five propositions identified in the design of the research programme above. Finally, subjects for further research are identified.

Chapter Two

Evolution And Current Use Of JIT Manufacturing

2.0 Introduction

This chapter identifies the circumstances surrounding the early use of JIT manufacturing, its evolution, and the subsequent spread of its use across the industrialised world. This provides an understanding of its goals and mechanisms. Current practice is reviewed. This summarises the effect of national, industrial, and company factors on the use of JIT manufacturing. The use of particular waste elimination techniques is examined and a set is identified which typifies current practice.

Disagreements and sources of confusion between definitions of JIT manufacturing are presented. A model of JIT manufacturing is developed from an analysis of its evolution and use. This defines, or limits, what is considered within the term JIT manufacturing throughout this thesis.

2.1 Evolution

JIT manufacturing formally began at the Toyota Motor Company. Their first vehicle was designed from features of a Ford chassis, a Chevrolet engine, and a Chrysler body. The company's objective was to develop in-house design skills, and a production system for small volumes capable of accepting frequent design changes. Universal machine tools and small stamping presses were used to easily adapt to model changes. The need for improvement was demonstrated in the 1930's by Toyota's first vehicle which broke down on route to the showroom (Cusumano 1988).

During 1937 Taiichi Ohno of Toyota was surprised to learn that on average it took around nine Japanese to do the work of one American. He set himself the target of a ten-fold increase in productivity (Ohno 1988b: 66). He concluded that the Japanese were wasting something. This idea produced the guiding philosophy of the Toyota Production System; continuous improvement through the thorough elimination of waste (Ohno 1988a: 3). Seven forms of waste were identified: motion; waiting time; overproduction; processing time; rejects; inventory; and transport (Suzaki 1987: 12-18; Ohno 1988a: 129; Shingo 1989: 191; and Harrison 1992: 34-38). Practical industrial examples identified during this research are given in Table 2.1. Thorough elimination of waste allows additional work to be performed in the time saved, giving improvements in productivity, Figure 2.1.

Waste	Examples and causes
Motion	Finding jigs, tools, cutters, and lifting equipment; cleaning jigs twice
Waiting Time	Delays due to shortages; waiting for maintenance, crane, material, and instructions; minding machine during cutting cycle
Overproduction	Large batches; internal delivery schedules with time buffers
Processing Time	Air-cutting; machine adjustments during cycle; reduced speed due to condition of tool, cutter, jig, and machine
Rejects	Condition of jigs; communication between shifts; imprecise documentation
Inventory	Queues for inspection; dead or obsolete stock; long setups; poor inventory control
Transport	Material to distant machines; jigs from remote storage location; to and from inspection

Table 2.1: Practical examples of the seven wastes identified during this research

2.1.1 Low Volume, High Variety, and Low Capital

The Japanese automotive industry continued to manufacture in very low volumes compared to the US competition until after the Second World War. At the end of the war, the small Japanese domestic automotive market demanded a wide variety of vehicles: large trucks; small trucks; luxury cars; and small cars. The economy was short of capital and foreign exchange which precluded large purchases of modern production facilities from overseas suppliers (Womack, Jones, and Roos 1990: 49-

50). Hence, Toyota worked with low volume, high variety demand, and low capital requirements.

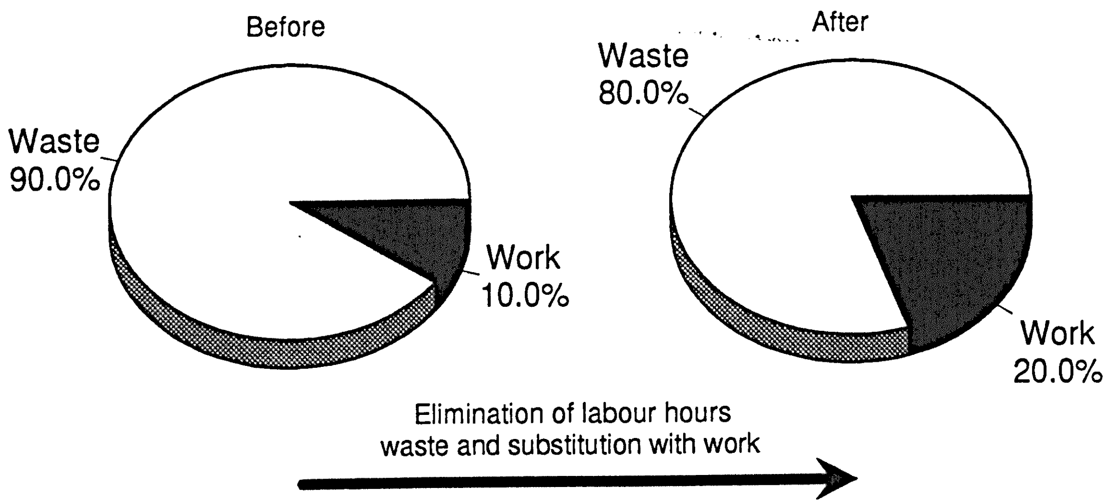

Figure 2.1: Productivity improvement through the elimination of waste

The exhaustion of credit led to the dismissal of one quarter of the Toyota Motor Company workforce in 1949. Terms for those remaining included guaranteed lifetime employment, and pay graded by duration of company service and linked to profitability. These managerial actions encouraged employee involvement in the active promotion of improvement and flexible work assignments (Womack, Jones, and Roos 1990: 49). Lifetime employment guarantees made the improvement of people utilisation over machine utilisation a high priority. The need to increase productivity was further highlighted by the Allied armies who had claimed that US productivity was still eight times greater than in Japan at the end of the war (Ohno 1988b: 67-68). Autonomation was an approach developed and used where a task would be performed by a machine (automation), and devices that could distinguish between normal and abnormal conditions would be added to the machine to prevent the production of defects (Ohno 1988a: 6). Operators no longer watched machines, the wastes of waiting time and defects were reduced, and productivity improved.

Low production volumes, high product variety, and tight capital restrictions demanded fast and simple die change methods to allow production workers to change dies every two or three hours instead of two or three months. Experimentation on second hand US presses resulted in setup times of minutes, instead of one day. Shingo (1989: xxiii-xxv; 43-46) identified three stages in the development of the waste elimination technique of fast and simple changeovers, or setup reduction. The identification of internal and external setup occurred in 1950, the conversion of internal to external setup followed in 1957, and 1970 led to reducing the internal and external elements. The benefits of the elimination of inventory carrying costs in a capital deprived economy became apparent.

Demand increase during the Korean War during the early 1950's and limited the availability of additional workers. Production levelling was developed to minimise the disruption of stop-go production at the assembly line (Ohno 1988b: 68-69): if 1,000 of a particular part was required each month, then 40 parts should be made on each of 25 days, and one piece every 12 minutes of a 480 minute workday (Ohno 1988a: 12). To improve productivity the layout of equipment was arranged according to the sequence of the processes. One operator worked several machines (Ohno 1988a: 11).

2.1.2 Assembly Lines

In 1950 Ford's River Rouge assembly plant used assembly operators, non-working foremen, support staff functions, and a covering workforce for the absent assemblers. Inspection and rework was a substantial end of line activity. Toyota demonstrated that assembly operators were the only people adding value and could do the jobs of the specialists. A team were given a range of operations and worked out the best way to perform them. Additional staff functions given to the team included housekeeping, minor tool repair, and quality checking. Next, dedicated time was allocated to allow the team to generate improvements. Finally, linestop facilities were added so team members could highlight problems in real time to engineers and managers, and problem solving approaches were introduced to help generate solutions. Rework levels reduced and product quality improved as sources of variation in the manufacturing systems were removed (Womack, Jones, and Roos 1990: 55-57). These changes required education, training, skilling, and a team-based form of employee organisation.

2.1.3 Supply Chains

Contemporary US and European practice was for high volume automotive assemblers to pursue bureaucratic command structures using vertical integration to control the thousands of discrete parts required throughout the supply chain. Lower volume assemblers relied more heavily on external suppliers. Engineering functions of automotive assemblers designed parts and sent drawings to suppliers with little other information about the finished product. Suppliers provided bids for short term contracts. There was little incentive or opportunity for suppliers to improve part designs. Suppliers did not cooperate between each other as they were in competition. Improvement of product design, supply, and production by suppliers was actively blocked.

Toyota wanted to provide incentive and opportunity for suppliers to improve design, supply, and production of parts. They organised a set of first tier suppliers each with a strong product engineering ability and gave them responsibilities for different components. Part performance and financial specifications were given to suppliers who provided the detailed design. A second tier of suppliers each with strong process engineering and plant operation ability was formed by first tier suppliers. Contractual arrangements between Toyota and their suppliers allowed each to retain a proportion of the benefits arising from improvements they were expected to achieve. Product design, supply and production improved continually, and further waste was eliminated (Womack, Jones, and Roos 1990: 57-62).

The kanban system (Esparrago 1988; and Schonberger 1983b) was developed from observation of US supermarkets (Suzaki 1987: 147-150) and newspaper reports of US aircraft production (Cusumano 1988). Initially kanban cards were used as signals to workers to transport or produce materials (Sugimori, et al 1977). This achieved synchronised operations within and between major stages of production such as machining and assembly by visually controlling the movement and production of parts, and reduced the waste of overproduction. It was first applied and proven around 1953 (Ohno 1988a: 28). Toyota began to teach its associate companies about the kanban system in 1965 (Shingo 1989: 233). Full installation from the first application required a period of twenty years. Facility reliability and rejects could cause difficulties in a manufacturing system with low buffer inventory levels. Waste elimination techniques including preventive maintenance and quality improvement at source were developed to allow the system to maintain production and achieve short leadtimes. These included indicator lights, or andon systems, established in 1957, and in 1962 mistake proofing devices to prevent the production of defects (Cusumano 1988). A multiplying effect, reducing the level of waste in the manufacturing system, was established as more waste elimination techniques were applied and further use of those existing was increased.

2.1.4 Other Manufacturers

With the exception of Nissan (Cusumano 1988), Japanese industry did not take significant notice of the development of the Toyota Production System until the company continued to be profitable during the scaled down production that followed the 1973 oil crisis (Ohno 1988b: 95). The use of waste elimination techniques from the Toyota Production System was spread across Japan through industrial groupings (or kyoryokükai - Turnbull, Oliver, and Wilkinson 1992), supply chains, and interest groups. For example, the Sumitomo group offer to help Mazda required the Hiroshima plant to incorporate many of the features of the Toyota Production System (Womack, Jones, and Roos 1990, 68). Another example was Kawasaki Heavy Industries who asked Toyota for assistance in 1976. Five engineers from Kawasaki went to Toyota. They implemented a pilot study in the final assembly and machine shop at the Kawasaki Akashi plant. Within one year, inventory, scrap and productivity were improved by 30%. Between 1977 and 1981 inventory reduced from 15 days to 3.2 days (Hall 1982). Derivatives of the Toyota Production System, including the Kawasaki Production System (KPS), the Canon Production System (Dyer 1987), and Synchro-MRP of the Yamaha Motor Company (De Toni, Caputo, and Vinelli 1988; Schonberger 1983a) were developed. These contained features of the Toyota Production System and introduced additional elements. Collectively, such approaches can be referred to as Japanese Just In Time Production Approaches (Schonberger 1982b).

As Japanese manufacturers became more prominent and significant in world trade, their approach to manufacturing management was increasingly discussed in literature. For example, Drucker (1971) described features of Japanese management practice, including lifetime employment, and continuous education, training, and skilling, and Sugimori, et al (1977) presented elements of the Toyota Production System. Towards the end of the 1970's, another oil shock caused problems for national economies. Japanese companies appeared to perform well during this period, and Western companies with manufacturing bases in Japan, such as Xerox, became more interested in Japanese JIT Production Approaches (Harrison 1992: 14). Hayes (1981) and Wheelwright (1981), together with managers from General Electric (GE), visited companies across a range of industries to identify causes for the success of Japanese manufacturers. Their conclusion was that discipline and consistency in operations were the real causes. They produced descriptive anthropological-style accounts of Japanese JIT Production Approaches. These provided anecdotal information of the differences between contemporary US and Japanese manufacturing management but offered little explanation as to why or how the features described should improve performance. Hayes (1981) also identified features in the visited companies that included a clean orderly workplace, inventory reduction, prevention of problems, buyer-supplier relationships, and continuous improvement. These were recognisable in the discussion of the Toyota Production System by Sugimori, et al (1977). These and other features were later described and their significance explained in the descriptions of JIT manufacturing by Schonberger (1982a; 1986), Hall (1983), Monden (1983; 1994), Ohno (1988a), Shingo (1989), Womack, Jones, and Roos (1990), and Harrison (1992).

With the Automotive Industry Action Group (AIAG) as a further catalyst, the use of JIT manufacturing was spread across the US. Outside the automotive industry, Omark Industries, Black and Decker, and Hewlett Packard are amongst the best known early US JIT pioneers. JIT manufacturing spread into Canada and Europe through divisions of US based corporations (Hay 1988:11). GE were among the first outside of Japan to mount a JIT campaign. Two GE plants had JIT programs in 1980, ten in 1981, twenty in 1982, and forty in 1983 (Sepehri 1986: 1).

During October 1983 the American Production and Inventory Control Society (APICS) announced the launching of its Zero Inventory (ZI) crusade. The need was identified as US companies were not matching the productivity gains made by other countries, notably Japan. The Repetitive Manufacturing Group Special Interest Group (RMG-SIG), whose primary mission was to promote the concepts of JIT manufacturing among repetitive manufacturers, was formed and began to hold meetings and visit companies. APICS began to send study missions to Japan. Finally, the ZI committee developed and presented educational presentations to the industrial communities of the US (Sepehri 1986: 23-26).

Use of Japanese JIT Production Approaches was further driven by mechanisms including Japanese US automotive transplants (Hall 1982; Schonberger 1982a), joint ventures including NUMMI between Toyota and General Motors (Sepehri 1986), CAMI Automotive between Suzuki and General Motors, and Diamond Star between Chrysler and Mitsubishi (Berggren 1993), and reaction to its use by competitors and customers (Im, and Lee 1989). Derivatives, such as ZIPS (Zero

Inventory Production System), MAN (Material As Needed), MIPS (Minimum Inventory Production System), Stockless Production (Keller, and Kazazi 1993), CFM (Continuous Flow Manufacturing) (Schonberger 1986: 60, and Beal 1988), Nick of Time (Ansari, and Modarress 1986), Frugal Manufacturing (Schonberger 1987), and Keep Materials Moving Manufacture (Bicheno 1991: 3) were developed. These can be collected under the term Western Just In Time Production Approaches. The development of JIT manufacturing from Toyota, via other Japanese companies, and including Western companies is shown in Figure 2.2.

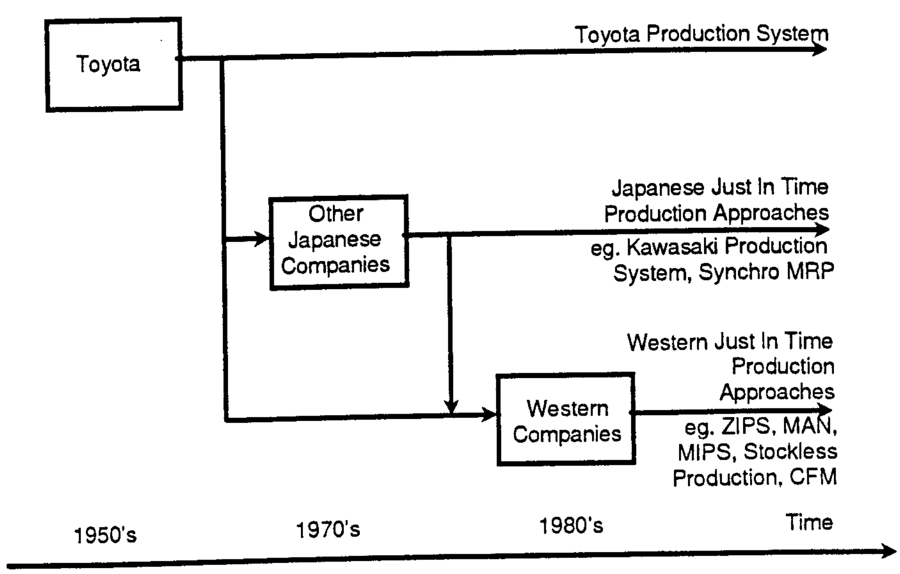

Figure 2.2: Development of JIT manufacturing

2.1.5 Summary

The Toyota Production System used Ford's River Rouge plant as a case study. Both involved low inventory levels and short leadtimes. However, each system achieved these by different means. Ford pursued the elimination of variation in manufacturing using a command economy, scientific management, and elimination of product variety. This form of production relied on dedication of facilities to standard products (Schonberger 1986: 7; Hayes, Wheelwright, and Clark 1988: 45). Ford did not solve the productivity dilemma of how to avoid paying a productivity penalty as the cost for increased product variety (Houndshell 1984). The Toyota Production System was developed to meet the goals of high variety, low capital requirement, and high labour productivity. It pursued continuous improvement through the thorough elimination of waste as the guiding philosophy.

Waste elimination techniques including multiskilling, autonomation, setup reduction, production levelling, layout improvement, pull control/kanban systems, visual control, housekeeping, and quality at source were developed and applied to enable small batch manufacturing. These were enabled by managerial actions, or support levers, such as lifetime employment, education, training, skilling, dedicated time scheduled for generating improvement, distributed responsibility for quality, opportunity for improvement distributed throughout supply chain, and teamworking. These covered a span of the manufacturing process including design, supply, production, distribution, and sales and marketing. The support functions of facility maintenance, quality systems, engineering, and employee organisation were also affected. They achieved improved productivity, quality, and leadtime. These reduced product cost.

Such was the extent of productivity improvement through the elimination of waste at Toyota that a productivity deficit of 9 to 1 with US automotive competitors (Ohno 1988b: 66) in the 1940's was turned into a 2 to 1 productivity surplus in the 1980's (Womack, Jones, and Roos 1990: 81). In the competitive Japanese automotive industry Toyota also consistently outperform all indigenous competitors (Delbridge, and Oliver 1991).

2.2 Current Practice

Many major industrial regions have been the subject of surveys on the use of JIT manufacturing, Table 2.2. However, JIT was not defined in the same way by all authors and respondents of surveys (Procter 1995), there were differences in the questions asked, and there is an absence of a standard set of terminology (Golhar, and Stamm 1991). The results of any survey of JIT users should be considered as preliminary as most firms have limited experience with JIT and do not completely understand its full impact on the organisation (Celley, et al 1986). These factors limit the comparisons that can be made between and the conclusions drawn across surveys. Most findings are mixed. Despite this, there are areas where findings from several surveys converge on a common set of conclusions. One instance of this regards which JIT manufacturing waste elimination techniques are commonly exploited.

Survey	Region
Voss (1984)	UK
Ansari (1986)	US
Celley, Clegg, Smith, and Vonderembse (1986)	US
Voss, and Robinson (1987)	UK
Cheng (1988)	Hong Kong
Crawford, Blackstone, and Cox (1988)	US
Wildemann (1988)	Germany
Im, and Lee (1989)	US
Morris, and Kim (1989)	Korea
Williams, Williams, and Haslam (1989)	Japan, UK
Gilbert (1990)	US
Giunipero, and Law (1990)	US
Golhar, Stamm, and Smith (1990)	US
Womack, Jones, and Roos (1990)	Asia, Europe, Japan, US
Ahmed, Tunc, and Montagno (1991)	US
Billesbach (1991)	US
Billesbach, Harrison, and Croom-Morgan (1991)	UK, US
Daniel, and Reitsperger (1991)	Japan, US
Delbridge, and Oliver (1991)	Europe, Japan, US
Freeland (1991)	US
Bartezzaghi, Turco, and Spina (1992)	Italy
Keller, Kazazi, and Carruthers (1992)	Europe
Lee (1992)	Korea
Norris (1992)	US
Baldwin, and Gagnon (1993)	US
Clarke, and Mia (1993)	Australia
Lawrence, and Lewis (1993)	Mexico
Sohal, Ramsay, and Samson (1993)	Australia
White (1993)	US
Chang, and Lee (1995)	US
Procter (1995)	UK
Hum, and Ng (1995)	Singapore
Spencer, and Guide (1995)	US

Table 2.2: Summary of regions surveyed for use of JIT manufacturing

2.2.1 Macro Environmental Factors Affecting JIT Use

Surveys have investigated the effects of a range of factors on the use of JIT manufacturing. These factors include the country of factory location, industry type, company size, and manufacturing process type (eg. project/jobbing/line/continuous process, Hill 1985: 81).

Voss, and Harrison (1987) concluded that most exporting companies in Japan use JIT techniques to varying degrees. Several surveys of developed industrial nations have agreed that 30-40% of companies are using JIT in some form, with more planning its use (Gilbert 1990; Bartezzaghi, Turco, and Spina 1992; and Clarké, and Mia 1993). Some surveys have differed widely with this, but they tend to investigate specific industries within countries. For example, Celley, et al (1986) found that 108 of 131 US automotive manufacturers (82%) had implemented JIT in some form. A comparison between the UK and the US showed that US companies using JIT produced a much greater proportion of their products using JIT practices than was the case for UK companies (Billesbach, Harrison, and Croom-Morgan 1991). There was little information on newly industrialised or developing nations, however, South Korea seems to use JIT much less than developed nations with only 5-6% of manufacturers pursuing JIT (Lee 1992). This demonstrates large differences in the use of JIT manufacturing according to the country of factory location. Whilst Japan is the most developed in its use, other Western industrialised countries are increasing their use of JIT. Newly industrialised and developing countries appear to be the least developed users of JIT, although this has not been widely studied.

In the case of companies in Singapore, Hum, and Ng (1995) found that overseas ownership was more likely to result in the use of JIT manufacturing. A similar, but less dramatic effect was found in the UK, Voss, and Robinson (1987). This is consistent with the dissemination of JIT manufacturing by multinational companies into other countries. However, no significant similar effect was found with companies in Italy (Bartezzaghi, Turco, and Spina 1992).

Particular industries are repeatedly identified in different nations as forerunners in the level of use of JIT manufacturing. Voss, and Robinson (1987), Crawford, Blackstone, and Cox (1988), Im, and Lee (1989), Bartezzaghi, Turco, and Spina (1992), Clarke, and Mia (1993), and Hum, and Ng (1995) noted that automotive, electronic, computer, and machinery industries are the most frequent users in the cases of the UK, US, Italy, Australia, and Singapore. Clarke, and Mia (1993) also noted that primary metals/concrete industries were the least frequent users. Schonberger (1984) demonstrated many other industries have applied JIT manufacturing. Different products including locomotives, dishwashers, high vacuum circuit breakers, jet engines, generators, light bulbs, coffee makers, and others are made using JIT manufacturing within General Electric alone. These represent high and low volume, high and low variety, discrete and process, make to order and make to stock, and smokestack and light assembly. According to Sohal, Ramsay, and Samson (1993) there was no correlation between level of success of JIT implementation and industry sector in their study of Australian companies, and hence it would appear that, as with the case of General Electric, JIT is widely applicable.

Surveys do not specifically identify the manufacture of commercial aircraft, but use more general Standard Industrial Classification (SIC) divisions (ie. manufacture of other transport equipment) instead of the more specific SIC groups or classes (ie. manufacture of aircraft and spacecraft) (Central Statistical Office 1992). Moras, Jalali, and Dudek (1991) showed that around 15% of 266 papers published between 1977 and 1990 in a wide range of large circulation journals were case studies. These did not contain clear cases of commercial aircraft manufacturers. Further case studies are also presented in conferences and seminars, but these are not as widely circulated. Hence the use of JIT manufacturing in the commercial aircraft manufacturing industry is not clearly shown in literature. However, the interest in the application of JIT manufacturing within the industry, as shown earlier, is particularly high.

The effect of company size is complicated by the different methods of determining size, such as volume of sales and number of employees. Most frequent use of JIT was found in large and medium sized companies by Voss, and Robinson (1987) and Im, and Lee (1989). Ahmed, Tunc, and Montagno (1991) also suggested that small firms are less likely to implement JIT. Gilbert (1990) reported that medium and smaller companies (sales <$100M) were more widely adopting JIT. This had been predicted by Im, and Lee (1989) who expected that larger companies would require their suppliers to adopt JIT practices. Bartezzaghi, Turco, and Spina (1992) concluded that company size did not significantly influence the adoption of JIT. However, Clarke, and Mia (1993) demonstrated that when ranked by number of employees a consistent drop from 60% of small companies to 30% of very large companies used or were planning to use JIT. Celley, et al (1986) demonstrated that when ranked by number of employees a consistent rise from 53% of small US automotive companies to 90% of very large US automotive companies had implemented JIT, although this was not statistically significant. Variations between the findings of the surveys may be explained by different questions being asked, and different or unstated classifications of companies as small, medium, large, or very large. Overall the effect of company size on the use of JIT is not clear.

Giunipero, and Law (1990) identified that job shop and batch manufacturers were more likely to perform organisational change during the process of JIT implementation than more repetitive manufacturers. However, according to Celley, et al (1986), the use of JIT does not appear to be influenced by the type of processes a firm uses (ie. continuous flow, assembly, batch, or job shop). Ahmed, Tunc, and Montagno (1991) also noted that different manufacturing process types did not seem to be associated to the level of JIT use.

Only the effect of country of factory location and industry type appears to have clearly influenced the level of JIT implementation across the industrialised and industrialising world. This supports the conclusion of Ahmed, Tunc, and Montagno (1991) that "the data suggest that the process [of JIT manufacturing] is, in fact, quite robust and that many of the commonly held limitations of JIT may be incorrect", and Moras, and Dieck's (1992) assertion that JIT techniques are applicable in almost any circumstance.

2.2.2 Use of waste elimination techniques

Voss, and Robinson (1987), Im, and Lee (1989), Gilbert (1990), Bartezzaghi, Turco, and Spina (1992), Sohal, Ramsay, and Samson (1993), White (1993), and Hum, and Ng (1995) listed 10 to 31 specific JIT waste elimination techniques and the frequency with which the respondent companies to surveys had used, or were planning to use. Although each survey investigated the use of different waste elimination techniques, these surveys consistently identified a set of nine particular waste elimination techniques, Table 2.3, which represent a practiced core. These findings are supported by the more general JIT texts (Schonberger 1982a; 1986; Hall 1983; Monden 1983; 1994; Dyer 1987; Suzaki 1987; Hay 1988; Ohno 1988a; Shingo 1989; Womack, Jones, and Roos 1990; and Harrison 1992).

Others such as visual control (including standard operations (Ohno 1988a: 66-67; Sekine, and Arai 1992: 129-147; and Edwards, Edgell, and Richa 1993) and andon systems), housekeeping/4S/5S/6S/workplace organisation (Dyer 1987: 78-80; Ohno 1988b: 117-119; and Kobayashi 1990), pull control/kanban, and autonomation/ autonomous defect control are suggested by JIT texts and the evolution section earlier in this chapter. Such additional techniques would not have been identified by the surveys as they were not widely included in their investigations. The identified core of nine practiced waste elimination techniques, Table 2.3, typify the current practice of JIT manufacturing.

The Nine Core Practised Waste Elimination Techniques	a	b	c	d	e	f	g
Multiskilling or flexible or cross-trained workforce and job enlargement or enrichment	1	3	3	1	8	3	5
WIP reduction and small lot sizing	2	1	2	8	4	-	3
JIT purchasing	8	4	1 and 2	6	7 and 23	4	12 and 15
Total Productive Maintenance/ Preventive maintenance	4	8	10	8	12	9	4
Setup reduction	6	-	6	11	2	1	7
Product simplification or component standardisation or product modularisation	3	-	15	3 and 15	-	-	-
Quality at source or operator centred quality control	9	-	5 and 17	-	1 and 3	2 and 8	8, 10, 18 and 20
Levelled and mixed production	14	10	-	10	-	10	6
Layout improvement: cellular manufacturing or group technology or dedicated lines or "U" shaped lines	11	5, 11 and 12	9 and 21	12	4, 10 and 12	5 and 6	11 and 21

a. Voss, and Robinson (1987) out of 17 waste elimination techniques
b. Im, and Lee (1989) out of 23 waste elimination techniques
c. Gilbert (1990) out of 31 waste elimination techniques
d. Bartezzaghi, Turco, and Spina (1992) out of 21 waste elimination techniques
e. Sohal, Ramsay, and Samson (1993) out of 24 waste elimination techniques
f. White (1993) out of 10 waste elimination techniques
g. Hum, and Ng (1995) out of 21 waste elimination techniques

Table 2.3: The nine core practiced waste elimination techniques from seven surveys

2.3 Definitions

Since the first widespread publications discussing JIT manufacturing, a variety of brief definitions have been proposed. The lack of agreement on a clear definition for

JIT manufacturing identified by Keller and Kazazi (1993), Bartezzaghi, and Turco (1989), and Safayeni, et al (1991) causes problems in the study and use of JIT manufacturing: with no consensus on a definition, it is difficult to know what to study and/or use, and how to interpret secondary sources.

Sources of confusion between definitions of JIT manufacturing include:

- different definitions consider JIT as: a philosophy; a methodology; an objective; a problem solving technique; a manufacturing strategy; a purchasing strategy; and a set of tools;
- different spans of the manufacturing process are considered: design; supply; production; distribution; and sales and marketing;
- various elements of support functions are raised: employee organisation; quality systems; engineering; accounting; and facility maintenance;
- some definitions fail to uniquely identify JIT manufacturing from alternative approaches to manufacturing management, such as Materials Requirements Planning (MRP), Manufacturing Resource Planning (MRP II), and Optimised Production Technology (OPT);
- the absence of standard terminology does not allow features to be uniquely identified. Different terms may be used to identify what may be considered as the same feature (eg. cellular manufacturing, group technology, "U" shaped lines, or dedicated lines), or different features may be collected under the same term.

These sources of confusion are demonstrated by example definitions, Table 2.4. These can present difficulties for the surveying of activity in the area (Procter 1995). No definition is likely to be generally accepted by a body of literature as diverse as that discussing JIT manufacturing, and the fluid nature of the subject itself provides additional difficulties (Cowton, and Vail 1994). The author's opinion is that others have attempted to summarise a highly complex subject in a statement that is too brief. This causes the omission of information, which leads readers to employ interpretation, and this results in differences in opinion and confusion.

Through the remainder of this chapter a model of JIT manufacturing is developed which is based on analysis of the evolution and use of JIT manufacturing, summarised above. This is to ensure that students and practitioners of JIT manufacturing alike recognise the model. The sources of confusion with other definitions, identified above, will be closely considered throughout the development of the model. A description of JIT manufacturing will be presented.

Author(s)	Definition
Voss, and Robinson (1987)	JIT may be viewed as a production methodology which aims to improve overall productivity through the elimination of waste and which leads to improved quality. In the manufacturing/assembly process JIT provides for the cost-effective production and delivery of only the necessary quality parts, in the right quantity, at the right time and place, while using a minimum of facilities, equipment, materials and human resources. JIT is dependent on the balance between the stability of the users' scheduled requirements and the suppliers' manufacturing flexibility. It is accomplished through the application of specific techniques which require total employee involvement and teamwork.
Graham (1988)	A management philosophy or toolbox of techniques. Based on making a significant improvement in operating efficiency through reduced inventory levels, lead times and overheads.
Im, and Lee (1989)	The JIT system is a concept or philosophy which employs as tools several production management practices such as setup time reduction, cellular manufacturing, level production planning, preventative maintenance, multifunctional workers, quality circles, kanban, JIT purchasing, etc. Because of its very nature, each company must develop its own JIT system.
Turnbull, Oliver and Wilkinson (1992)	Matching the market and the manufacturing system, eliminating waste in all forms.
Fielder, Galletly, and Bicheno (1993)	JIT can be viewed from a number of different angles including people (attitudes, motivation, education in philosophy of JIT, training in procedures) and engineering (layout, product design for manufacture, setup reduction).
Sohal, Ramsay, and Samson (1993)	JIT is essentially a philosophy more than a series of techniques, the basic tenet of which is to minimise cost by restricting the commitment to expenditure in any form, including manufacturing or ordering materials, components, etc, until the last possible moment.

Table 2.4: Example definitions of JIT manufacturing

2.4 Pyramidal Model

The structure of the model for JIT manufacturing is represented by a pyramid, Figure 2.3. It is founded on the elimination of the seven wastes and developed by the author in the specific manufacturing context of the company (or part thereof) in which JIT manufacturing is being implemented. The pyramid has three levels: support levers; waste elimination techniques; and performance measures. As the range of support levers used and sustained increases, a wider variety of waste elimination techniques can be applied in the specific manufacturing context, and greater progress will be made regarding the range and reach of performance improvements measured. Hence, increasing the dimensions of the pyramid symbolises improving the performance of the manufacturing system. Each element of the model is discussed below.

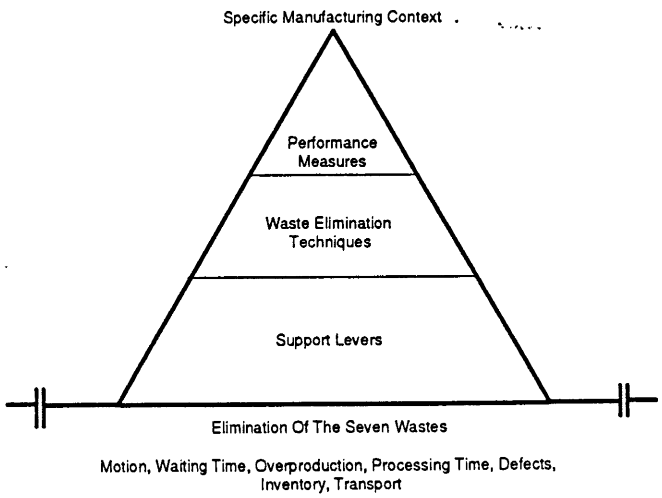

Figure 2.3: Pyramidal model structure

2.4.1 Basis: Elimination Of The Seven Wastes

JIT manufacturing is based on continuous improvement through the thorough elimination of waste. The seven wastes of motion, waiting time, overproduction, processing time, defects, inventory, and transport, were discussed above. This is the foundation for the subsequent levels.

2.4.2 Level One: Support Levers

A support lever is a managerial action which promotes the use of waste elimination techniques. Support levers were identified throughout the discussion of the evolution of JIT manufacturing. Fourteen examples of support levers are shown in Table 2.5. Eleven of these are based on the evolution of JIT manufacturing and others were identified from industrial training conducted during this research. Surveys into JIT implementation in various countries and industries found that without the selected use of such support levers it is unlikely that the application of waste elimination techniques would be successful (Lee, and Ebrahimpour 1984, 1987; Golhar, Stamm, and Smith 1990; Harber, et al 1990; Ahmed, Tunc, and

Montagno 1991; Billesbach, Harrison, and Croom-Morgan 1991; Mehra, and Inman 1992; Sohal, Ramsay, and Samson 1993).

Support Lever
Guaranteed lifetime employment, and other forms of employment security
Reward systems linked to profitability or other desirable conditions or features. eg. skills, quality, or rate of improvement
Organisation of people into teams giving communication with design, engineering, sales and marketing, and accountancy
Opportunity and responsibility for quality distributed throughout company
Training in the procedures of specific JIT waste elimination techniques
Problem identification and solving techniques to generate improvement ideas
Dedicated time scheduled for generating and implementing improvement ideas
Education in, and demonstration of, general principles of JIT manufacturing
Skilling to improve competence in the core processes across a wider body of people
Opportunity and responsibility for improvement distributed throughout supply chain
Organisation into supplier tiers and use of partnerships with suppliers
Clear and used two way communication networks to and from all parts of the company and supply chain
Provision of budgets to support improvements
General working conditions

Table 2.5: Fourteen examples of support levers for JIT manufacturing.

Successful support requires the balanced use of a range of support levers. Use of only one will provide little support, irrespective of the quantity applied, whilst a diverse range will be more effective.

Support levers themselves are not the direct source of performance improvement. Instead, they are required to provide the knowledge and encouragement for waste elimination techniques to be successfully applied within a manufacturing system. The waste elimination techniques then reduce the level of waste in the manufacturing system and improve its performance (Mehra and Inman 1992; Ramarapu, Mehra, and Frolick 1995).

2.4.3 Level Two: Waste Elimination Techniques

The range of JIT manufacturing waste elimination techniques is wide (Bicheno 1991: 7), with over one hundred having been identified (Voss 1988). An exhaustive attempt to identify all waste elimination techniques in a model or definition for JIT manufacturing will result in confusion caused by the absence of standard terminology and the emergence of new techniques as JIT evolves with time. This would quickly invalidate an exhaustive model or definition. Hence, there is no intention in this thesis to provide a comprehensive listing of waste elimination techniques. These have been extensively discussed by major texts and the reader is directed at Schonberger (1982a; 1986), Hall (1983), Monden (1983; 1994), Dyer (1987), Suzaki (1987), Ohno (1988a), Shingo (1989), Womack, Jones, and Roos (1990), and Harrison (1992). Instead, a carefully selected core of waste elimination techniques will allow for interpretation of the model or definition to include those waste elimination techniques related to those in the core. An implementation which used waste elimination techniques not included in the core will almost certainly also use several core techniques, and the implementation would still be accurately described by the model.

The discussion of the current use of JIT manufacturing identified nine waste elimination techniques as the core practiced techniques, which typify current practice. The discussion of the evolution, supported by the major JIT texts above, highlighted a further four. This generates a proposed core of thirteen techniques which were important in the development of JIT manufacturing and also typify current practice. The combined core of thirteen waste elimination techniques are listed in Table 2.6.

A wide span of the manufacturing process and support functions are affected by the thirteen core waste elimination techniques. Design, supply, production, distribution, and sales and marketing, employee organisation, quality systems, engineering, and facility maintenance each have a role in the implementation of the above. The absence of standard terminology presents problems to uniquely identify features and cannot be fully rectified in the space here. However, differing terms are grouped together where appropriate to reduce the problem.

The Thirteen Core Waste Elimination Techniques	Evolution	Base Theory	Use
Flexible/cross trained workforce and job enlargement/enrichment	✓	✓	✓
WIP reduction and small lot sizing	✓	✓	✓
JIT purchasing	✓	✓	✓
Total Productive Maintenance/Preventive maintenance	✓	✓	✓
Setup reduction	✓	✓	✓
Product simplification, component standardisation, and product modularisation	✓	✓	✓
Quality at source and operator centred quality control	✓	✓	✓
Levelled and mixed production	✓	✓	✓
Layout improvement: cellular manufacturing/group technology/dedicated lines/"U" shaped lines	✓	✓	✓
Visual control including standard operations and andon systems	✓	✓	-
Housekeeping/4S/5S/6S/workplace organisation	✓	✓	-
Pull control/kanban	✓	✓	-
Autonomation/autonomous defect control	✓	✓	-

Table 2.6: The thirteen core JIT manufacturing waste elimination techniques.

Successful use of a waste elimination technique allows waste to be substituted with additional work, and overall system productivity is increased, Figure 2.1. The extent to which this is achieved is monitored through the use of appropriate performance measures.

2.4.4 Level Three: Performance Measures

The use of traditional performance measures and measurement (including accounting) systems with JIT manufacturing has been frequently discouraged (Kaplan 1984; 1986; Ballew, and Schlesinger 1989; Lea and Parker 1989; Williams, Williams, and Haslam 1989; and Crawford, and Cox 1990). One reason for this is because cost accounting systems were designed for an environment of mass production of standardised products where direct labour was a major element of product cost and overhead costs were low (Johnson and Kaplan 1987). Many companies compute and manage with the measures of labour efficiency and machine utilisation. These stimulate supervisors to keep operators busy, even producing unnecessary parts, and provoke large queues of inventory in front of machines. This clearly works against the process of the implementation of JIT manufacturing (Schmenner 1988). Fry (1995) presented an argument of how the implementation of JIT manufacturing can have a detrimental effect on a selection of financial ratios, and Plenert (1990) presented such a case where traditional performance measures halted a JIT implementation when some traditional financial ratios monitored by the company suffered due to inventory reduction. Novitsky (1986) provided further examples from case studies, and Crawford, Blackstone, and Cox (1988) identified other instances from a survey.

As no single performance measure can effectively guide and monitor a JIT implementation (Clarke and Mia 1993), a range of performance measures are required. There are no right numbers of measures for any organisation, but there are guidelines. There should be more than four and probably fewer than ten (Lynch and Cross 1991: 185). There are many specific performance measures that could be used to evaluate improvement in a JIT manufacturing system and their selection is an element of the performance measurement system design process. Bartezzaghi, Turco and Spina (1992) considered twenty-eight in their survey. Voss and Harrison (1987) identified key measures as: WIP level; quality; manufacturing leadtime; distance travelled; space utilisation; productivity; and cost. Bicheno (1991, 83) identified key measures as: production flow length; operators with multifunction skills; stock turns; inventory reduction; customer service; leadtime; and quality. Wisner and Fawcett (1991) proposed twenty-eight measures that they consider to be consistent with JIT manufacturing.

Research is needed in designing a comprehensive performance measurement system for the implementation of JIT (Goyal, and Deshmukh 1992). For the purposes of the pyramidal model of JIT manufacturing, a range of twenty-three performance measures was based upon the above to monitor the progress in the elimination of the seven wastes using the core of thirteen waste elimination techniques, Table 2.7. As will be shown in chapter six, the selection of these can be based on the relationship of the measures with the competitive criteria in which the company requires improvement.

Twenty-Three Key Performance Measures
Number of skills per operator/proportion of people with one skill, two skills, etc.
Raw material/work in progress/finished goods inventory/inventory turnover rate (level and trend)
Production batch size and transfer batch size (average)
Purchased batch size/number of deliveries per day/vendor leadtime/vendor quality
Number of suppliers (absolute and trend)
Proportion of purchasing budget/transactions in JIT deliveries
Machine downtime (hours)/breakdowns (events)/mean time to repair (hours)
Setup time (average) and changeover loss time (Sekine and Arai 1992: 14)
Number of part numbers per end product/number of end products per part number
Time from cause of defect to detection (average)
Right first time/rework/scrap (level and trend)
Material/tool/jig production flow length (per part and average)
Visual control audit (low/high and decreasing/increasing) (Suzaki 1993: 360-362, 424-427)
Housekeeping/4S/5S/6S/workplace organisation audit (low/high, and decreasing/increasing) (Dyer 1987: 80)
Manufacturing leadtime (level and trend)
Annual number of new product introductions
Time to introduce a new product (level and trend)
Delivery reliability (level and trend)
Stock turns (level and trend)
Labour productivity (direct and overall)
Labour turnover rate (direct and overall)
Product cost
Number of improvements proposed, accepted, and implemented (absolute and per person)

Table 2.7: Twenty-three key performance measures to monitor the elimination of waste using the core thirteen waste elimination techniques

2.4.5 Environment: Specific Manufacturing Context

The specific manufacturing context is the combination of the features of the people, machines, materials, processes, products and managerial policy, including the history of manufacturing improvement initiatives in living memory, that describe and differentiate one manufacturing system from another even within the same industry, company, and factory. Each specific manufacturing context could expect to present different issues throughout the implementation of JIT.

The relationships between the seven wastes, support levers, waste elimination techniques, and performance measures are not deterministic; they are complex and affected by the specific manufacturing context. This can be demonstrated by practical industrial examples identified during this research. Different combinations of support levers may be used to successfully promote a given waste elimination technique.

> Example 1. A case of setup reduction may be successfully promoted by support levers such as education and problem identification and solving techniques.

> Example 2. Another case may promote setup reduction using provision of budgets, organisation of people into teams, and the dedication of time for generating and implementing improvements.

Several wastes may be affected and in differing degrees by a given waste elimination technique, according to the specific manufacturing context.

> Example 3. Setup reduction may be achieved through actions such as repositioning tools required for the setup procedures. This reduces unnecessary motion, and may release sufficient capacity for increased numbers of setups to allow a reduction in batch sizes for a given production volume. This would reduce the waste of inventory and overproduction.

> Example 4. Setup reduction may release sufficient capacity for an increase in the number of setups and allow smaller batch sizes, but these may not be achieved as existing layout could demand a volume of transport which prohibits a reduction in batch sizes. The waste of inventory and overproduction would not be reduced.

> Example 5. Setup reduction may be pursued but may not release sufficient capacity to allow increased numbers of setups to allow smaller batch sizes. The waste of inventory and overproduction would not be reduced.

A given change in a performance measure may affect wastes in degrees that differ according to the specific manufacturing context.

> Example 6. In a specific manufacturing context, labour productivity may be increased as a consequence of less waste of defects, but processing time waste may remain unchanged. Therefore, increased labour productivity does not necessarily mean a reduction in the waste of processing time.

Example 7. In a second manufacturing context, labour productivity may be increased as a consequence of less waste of processing time, but the waste of defects may remain unchanged. Therefore, increased labour productivity does not necessarily mean a reduction in the waste of defects.

The specific manufacturing context is important to JIT manufacturing, and its implementation in a given case. Detailed understanding of the specific manufacturing context is required throughout the implementation of JIT manufacturing to determine: which support levers are required to promote which waste elimination techniques; how the approach to each waste elimination technique will affect the seven wastes; and how the readings of the performance measures are related to the seven wastes. The relationship between the waste elimination techniques and the performance measures can be more firmly related, by definition, as the performance measures indicate the degree to which a defined task or activity is performed.

2.4.6 Summary Of Pyramidal Model

A summary of the pyramidal model of JIT manufacturing is shown in Figure 2.4. This shows the five main components of: the basis (elimination of the seven wastes); the environment (the specific manufacturing context); and the three levels (support levers, waste elimination techniques, and performance measures), and under each of these headings lists the elements identified from the evolution and current use of JIT manufacturing, in chapter two. This includes fourteen support levers, thirteen waste elimination techniques, and twenty-three performance measures.

All of the interrelationships between the five main components of the model are non-deterministic, due to the unique combination of the elements within the specific manufacturing context. The exception to this is the interrelationship between some waste elimination technique and performance measure elements, which can exhibit deterministic relationships by definition.

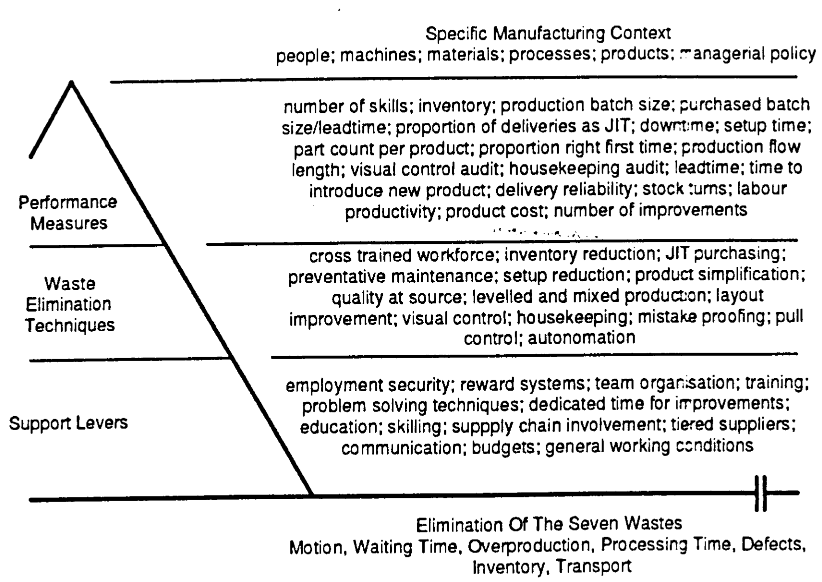

Figure 2.4: Pyramidal model summary

2.3 Conclusions

Taiichi Ohno visualised the scale of waste in manufacturing operations and identified the seven wastes of motion, waiting time, overproduction, processing time, rejects, inventory, and transport. Toyota developed and persistently applied a wide range of waste elimination techniques to provide continuous improvement through the thorough elimination of waste. Coupled with this were a variety of support levers, or managerial actions, such as education, training, guaranteed lifetime employment, and dedicated time scheduled for generating improvement. These covered a span of the manufacturing process including design, supply, production, distribution, and sales and marketing. The support functions of facility maintenance, quality systems, engineering, and personnel were also affected.

JIT manufacturing enabled its creator, the Toyota Motor Company, to improve quality, leadtime, cost, and turn around a nine to one productivity inferiority with US automotive competitors in the 1940's to a two to one productivity superiority in the 1980's. Toyota also consistently outperform all indigenous Japanese automotive manufacturers. A number of derivatives have been spawned from the Toyota Production System and these are used by other manufacturers in Japan, and the rest of the industrialised and industrialising worlds. The process appears to be quite robust, and capable of application in many environments beyond its birthplace of the automotive industry.

JIT manufacturing continues to be developed by practising engineers in live manufacturing environments in different manufacturing nations, in many companies, large and small, project shop to continuous process, and in a wide range of industries. There is no agreement regarding a clear definition of JIT manufacturing. However, from an analysis of the evolution and current use of JIT manufacturing, a model was developed by the author which defines what is considered within the term in this thesis.

Chapter Three

Implementation Of JIT Manufacturing

3.0 Introduction

The nature of the problem of JIT implementation is introduced in this chapter. Approaches to the implementation of JIT manufacturing are classified into a number of different types. These approaches are then summarised and evaluated. Difficulties and risks associated with each type of approach are identified. Based on this analysis, a favoured approach to the implementation of JIT manufacturing is identified.

3.1 Terminology

To recall the statement presented in the introductory chapter, according to the researcher, the process of JIT implementation in the context of this thesis is:

> the combination of collections of waste elimination techniques and support levers in concert to eliminate the seven wastes from the manufacturing system. It is the use of more than one waste elimination technique and support lever in concert with others for the purpose of waste elimination that constitutes inclusion as part of JIT implementation. The process of JIT implementation starts when the first waste elimination techniques and support levers are used in concert with the purpose of waste elimination. It is continually developed as additional waste elimination techniques and support levers are employed, or the use of existing waste elimination techniques and support levers is extended.

It can be deduced from this that JIT implementation does not have an end point. Instead, a starting point, a method, and a guiding objective can be identified.

To avoid confusion, particular use is made of the following terms throughout:

- the process of JIT implementation, or the implementation of JIT manufacturing, described above, is the act of combining collections of waste elimination techniques and support levers in concert to eliminate the seven wastes from the manufacturing system;
- a JIT implementation structure, or structure, presents a high level summary of the stages involved in JIT implementation, but does not identify lower level assistance;
- a guideline, is advice which is intended by the writer to assist those implementing JIT manufacturing at one stage or decision during the process of JIT implementation;
- a JIT implementation framework, or framework, is a coordinated set of guidelines within a defined structure which is intended by the writer to direct those implementing JIT manufacturing throughout the process of JIT implementation;
- an issue, or JIT implementation issue, is a factor which may influence decisions throughout the process of JIT implementation and are the consequence of the specific manufacturing context elements of people, machines, materials, processes, products, and managerial policy.

These terms are used explicitly throughout the remainder of the thesis and are not intended to be interchangeable or represent alternative meanings.

3.2 JIT Implementation Issues

The use of waste elimination techniques and support levers during the process of JIT implementation results in widespread changes to the manufacturing system. These changes can be affected by a diverse range of important issues (Celley, et al 1986). Literature identifies many issues as relevant to the implementation of JIT manufacturing from case studies, application surveys, literature surveys, simulations, and conceptual discussions. A small selection of implementation issues from literature is given in Table 3.1. This table is by no means exhaustive, as there are many implementation issues raised by other researchers that are not presented. However, it demonstrates the wide range of implementation issues that have been perceived to affect JIT manufacturing, and the large variance between different researchers regarding the issues identified as significant. The implementation issues vary in the extent to which they are environmental, and hence difficult to control, and the degree to which they can be influenced during JIT implementation.

Golhar, and Stamm (1991) concluded that there is little consensus among researchers regarding the relative importance of issues in JIT implementation after identifying twenty four implementation issues from 211 research papers. Ramarapu, Mehra, and Frolick (1995) also identified a lack of concord between researchers regarding the relative importance of implementation issues after identifying twenty eight issues from 105 research papers.

Using an application survey, Mehra, and Inman (1992) identified a correlation between the level of success of JIT implementation and two groups of implementation issues titled "JIT production strategy" (ie. setup reduction, in-house batch size reduction, Group Technology, cross-training, and TPM) and "JIT vendor strategy" (ie. vendor batch size reduction, sole sourcing, vendor leadtime reduction, and vendor quality certification). However, twenty implementation issues accounted for only one third of the variation in the success achieved by companies in seven performance measures. Hence, no single implementation issue has been demonstrated as dominant in the success or failure of JIT implementation. The effect of each issue on the implementation of JIT cannot be considered in isolation as it is how they combine that will determine progress in any given case. These relationships are not clearly understood and there is an absence of identifying correlations that may exist between critical implementation issues relating to JIT manufacturing (Keller, and Kazazi 1993).

The presence and significance of some implementation issues are influenced, though not predominantly determined, by macro environmental factors such as industry type and company size. The implementation issues identified as important to JIT manufacturing vary widely from one researcher to another. This indicates that the implementation issues are different in each case and their presence and significance are principally determined by the specific manufacturing context. This is supported by consideration of the implementation issues in Table 3.1.

JIT Implementation Issues

Sohal, Ramsay, and Samson 1993.
What was common to unsuccessful cases:
low management commitment/leadership
supplier difficulties
insufficient resources
departure of JIT instigator/enthusiast
other company difficulties
lack of employee training/involvement
lack of perseverance with difficulties
employee scepticism/resistance to change
need for TQM to complement JIT
What was common to successful cases:
sustained senior management support
employee involvement and support
systematic analysis/thorough planning
pre-existence of quality program
question and abandon traditional practices
belief in success/persistence
strong and committed JIT coordinator
tangible benefit/positive reinforcement

Mehra, and Inman 1992.
management commitment to JIT philosophy
formal means for suggestions
investigate/implement suggestions of merit
employees authority to halt production
education of top management
quality certification of suppliers
reduction in vendor leadtime
reduction in in-house lot sizes
reduction in vendor lot sizes
utilisation of sole sourcing
setup time reduction
formal preventive maintenance
utilisation of group technology
utilisation of quality circles
use of a consultant for implementation
cross training of employees
vision of the future
a JIT champion with authority
a JIT team to facilitate implementation
JIT implementation pilot project

Ansari 1986.
purchase small lots/frequent deliveries
drastic reduction of supplier numbers
long term relationships
early supplier involvement/support

Ansari, and Modarress 1986.
lack of support from suppliers
lack of top management support
low product quality
lack of employee readiness and support
lack of support from carrier companies
lack of engineering support
lack of communication

Clarke, and Mia 1993.
supplier or customer inflexibility
staff resistance to change existing system
production facilities reorganisation cost
prohibitive capital requirement
long supplier leadtimes
customer forecast inaccuracies
storage problems
change of staff
reevaluation of manufacturing strategy

Golhar, Stamm, and Smith 1990.
quality of incoming parts
unreliable delivery schedule
lack of vendor involvement
costly changes in layout of machinery
implementing smaller lot sizes
cost of employee training
convincing employees/unions of importance of JIT
lack of confidence in JIT
difficulty of monitoring inventory

Lee, and Ebrahimpour 1984.
management's support and understanding
management and labour responsibilities
training
department functions
supplier management
production layout and workflow
long term planning
stockholders
labour organisations
government support

Ahmed, Tunc, and Montagno 1991.
employee turnover rate
perceived cost of training for flexibility
skill requirements for jobs
firm size
top management commitment to resource allocation
quality improvement program with customers
percentage of customers using JIT

Spencer, and Guide 1995
setup reductions
lot size reductions
preventive maintenance
physical layout management
cross trained workers
effective capacity utilisation
plant wide program adoption of JIT methods
in-house quality
vendor lot size reductions
vendor leadtime reduction
vendor quality
sole sourcing
mutual respect
JIT seen as overall philosophy of business
JIT education throughout organisation

Celley, et al. 1986.
customer schedule changes
poor supplier quality
poor production quality (internal)
inability to change paperwork systems
storage of critical parts
supplier inability to deliver JIT
lack of employee commitment
inability to reduce setup time
inadequate equipment and tooling
surplus of non-critical parts
lack of top management commitment
labour contract problems

Im, and Lee 1989.
top management commitment
worker participation
education
level scheduling
reorganisation
nearby suppliers
supplier participation
reduction of setup time
old accounting practices
quality

Giunipero, and O'Neal 1988.
not suited to non-repetitive business
perception of business being different
distance from suppliers
instability of customer schedules
financial auditing requirements
no perceived benefits for suppliers

Finch 1986.
unable to motivate suppliers to change
limited money to invest in change
have to phase whole operation into JIT
know which aspects of JIT can work in the company

Hum, and Ng 1995
interface with existing manufacturing system
lack of internal expertise
problem in setup time reduction
poor information/data accuracy
lack of performance measure
problem in line balancing
lack of vendor support
lack of continuing education/training
poor forecasting
inability to meet schedule
frequent machine breakdown
problem in re-layout
employee's resistance to JIT
maintaining quality during implementation
problem in correct routeing
poor quality
problem in changing database
lack of top management commitment
problem with accounting practice
lack of management support

Table 3.1: Selection of JIT implementation issues

Particular implementation issues may be important at specific stages of implementation, and less significant at others. This was demonstrated by Safayeni, et al (1991), who identified four stages of the development of JIT implementation and particular implementation issues that were relevant at each stage. Level one is called education, or talking JIT, and the main issue is education. Level two is the pilot project, or test tube JIT, whose main issue is progress beyond an isolated project as this requires the cooperation and support of the rest of the organisation. Level three is modified JIT, or push-JIT, where JIT is implemented in only a small part of the production system and the main issue is the pressure to modify the JIT manufacturing system to interface with the non-JIT system. Level four is total JIT whose main issue is how the organisation can be restructured along product lines.

The lack of standardised terminology complicates interpretation of the work of the researchers. Terms used are frequently loose and not defined in the original sources. Analysis of literature generally depends on interpretation of the terminology (Ramarapu, Mehra, and Frolick 1995). This is demonstrated by the issue of management commitment, understanding, and support for JIT manufacturing. Mehra, and Inman (1992) defined it as the use of a formal means for listening, investigation of suggestions, operator authority to stop the line, and quality circles. Bicheno (1991: 73-74), described it as involving vision, time (to listen, guide, understand, encourage improvement), trust (for quality and regulation in a decentralised management system), understanding (of delays, bottlenecks, quality problems, difficulties, and opportunities), consistency, and resources. However, most other users of the term provide no clarification on its intended meaning.

In summary, there are many issues related to the process of JIT implementation that must be considered throughout. No implementation issue has been shown to be dominant. There is little consensus among researchers regarding the relative importance of the issues, and the relationships between them are not clearly understood. Although implementation issues are influenced by macro environmental factors, such as, industry type, company size, and manufacturing process type, they are different in each case and principally determined by the specific manufacturing context.

Hence, it is not feasible to forecast the presence and importance of a wide range of implementation issues for a general case. However, detailed knowledge of the specific manufacturing context will assist the identification of those implementation issues that are present and potentially significant in a given case.

3.3 The JIT Implementation Dilemma

The effects of JIT implementation on manufacturing systems can be wide reaching (Celley, et al. 1986) and extend throughout a manufacturing company and into its suppliers and customers (Lee, and Ebrahimpour 1984). The wide range and large number of waste elimination techniques and support levers associated with JIT manufacturing lead to dramatic changes in the appearance and management of manufacturing systems. A description by Bicheno (1991: 1) of before and after JIT implementation demonstrates some of the differences between traditional manufacturing management, organisation, and operation, and a mature implementation of JIT manufacturing.

> "Good performance in the 1980's was to deliver a container of products to a warehouse in time - meaning a few days early. The products themselves may well have contained defectives; but no matter, they would be sorted out by receiving inspection. If the customer was another manufacturer, that firm would have considered it normal to make adjustments to get the various components to fit together. Within the plant, batch production was the rule. Components would be placed in containers and moved by forklift to another workstation. The delivered components would themselves go into batches of product. At the end of the batch a few components might be left over, because the allowed scrap factor did not work out exactly. No matter. Take them back to the stockroom. Report the situation to the computer. The MRP system would correct for the extras the next time around. ("That's how computer power can help you", the system salesman said.) The final product would be out of the plant within two weeks, but one could not say exactly since there would almost certainly be delays while rush jobs were completed.
>
> "Consider the 1990's. Now a pallet of components must be delivered to the point of use within a time window of perhaps 15 minutes. All the components must be of perfect quality. The components themselves are of mixed specifications. They are arranged on the pallet in the exact sequence they will be used. The orientation must be correct to minimise handling waste. Once delivered, the components will remain on the pallet for less than 30 minutes. Internal material handling is often in containers small enough, and with the next operation close enough, to be moved by hand. At the end of the day the schedule will have been met exactly; no more and no less. It is not necessary to report each stage to the computer. The completed product will be out of the plant tomorrow and no "surprise jobs" will disrupt the schedule." (Bicheno 1991: 1)

Another representation of a similar scale of change as a result of JIT implementation is given by Heiko (1989), Table 3.2.

Stage Of Operations	Features Of A Mature JIT Manufacturing System
Receiving	do not inspect; do not store; order in amounts to be processed in a period; have material delivered directly to production; minimise paperwork.
Processing	do not inspect; do not rework; minimise process flow distance; minimise setup time; minimise lot size; operate with minimum WIP; minimise paperwork; do not produce extra units.
Outgoing	do not store; do not inspect; ship only perfect units; minimise paperwork.

Table 3.2: Features of a mature JIT manufacturing system (Heiko 1989)

The difference between traditional manufacturing management approaches and JIT manufacturing is so large that some view the only way to implement JIT is to dismantle the old system and start full JIT on another day. A preferable approach is to gradually phase in JIT (Miltenburg and Wijngaard 1991). This is supported by Pegler and Kochar (1990) and Fielder, Galletly, and Bicheno (1993) who state that all of the changes to many aspects of the production process required by the large set of waste elimination techniques and support levers of JIT manufacturing cannot all be implemented simultaneously and that it is wise to take a step-by-step approach to the implementation of JIT manufacturing. Many companies are pursuing a gradual, or phased, introduction of JIT manufacturing instead of a complete switch (Goyal and Deshmukh 1992).

The problem raised by gradual phased approaches to JIT implementation is to determine which waste elimination techniques or support levers should be applied, where in the manufacturing system, and when, in order to achieve competitive advantage (Lockamy and Cox 1991). Implementation of JIT is not a simple matter (Im and Lee 1989). As stated by Voss and Harrison (1987), "it is difficult to know where to start", or how to continue. This is the JIT implementation dilemma.

The JIT implementation dilemma is a result of the large size and complexity of the problem of JIT implementation. The rationalised core of thirteen waste elimination techniques identified, Table 2.6, presents over 17,000 options for the first four waste elimination techniques to be pursued, and more than 24,000 permutations in which the first four of fourteen support levers of Table 2.5 could be employed. The selection of appropriate waste elimination techniques and support levers is influenced by the specific manufacturing context and the wide range of implementation issues, such as those of Table 3.1.

3.4 Review Of JIT Implementation Structures

A small number of JIT implementation structures have been presented. These tended to be early contributions to guide the implementation of JIT manufacturing in Anglophone industrialised countries.

Youngkin (1984) proposed the following four stage JIT implementation structure for job shops:

1 - education. Understand the concepts, benefits, and techniques of JIT;
2 - analysis. Identify areas of opportunity, and develop a time phased plan;
3 - pilot program. Demonstrate real benefits;
4 - implementation. Once the pilot program has been successfully completed, programs throughout the plant are started.

Novitsky (1985) reviewed the introduction of JIT manufacturing in a consumer goods division of Phillips consisting of forty factories, and identified a single structure to take advantage of the learning curve of repeated JIT implementation across a large company. Four phases were identified:

1 - preliminary. Education of a limited number of people, and evaluation of the performance measurement system;
2 - self assessment. Middle/lower management identify shortcomings of the existing manufacturing system;
3 - develop a plan. Development of a detailed implementation plan with tasks and resources;
4 - implementation. Installation of the changes in policies, procedures, layout, and setup reduction. The final stage is recycled, as JIT is not achieved in one step.

Ansari (1986) provided a three phase implementation structure for JIT purchasing:

1 - learn. A learning process of reduce inventories, eliminate waste, and expose problems to solve;
2 - pilot. Pilot programs involving a small number of local suppliers and part numbers of high value of use and low volume with frequent line side deliveries;
3 - implement. Functional implementation.

These structures are not detailed in terms of the guidance offered, and do not present a solution to the JIT implementation dilemma, but simply provide a sequence of steps with minimal instruction.

3.5 Review of Prescriptive JIT Implementation Frameworks

The connection between the specific manufacturing context and the process of JIT implementation was investigated by Im (1989) who asked the following:

- is it possible to develop a globally prescriptive framework for JIT implementation?
- is there an ideal sequence of implementing certain JIT practices for each manufacturing process type (eg. project/jobbing/batch/line/continuous process, Hill 1985: 81)?
- should each company pursue a level of JIT implementation selectively, adopting JIT practices based on its manufacturing process type?

This section presents a summary of JIT implementation frameworks proposed in literature as answers to the first two questions above. The frameworks identify specific waste elimination techniques and support levers, and a sequence or schedule for their use. They are evaluated later in the chapter, together with the other approaches to the implementation of JIT manufacturing.

Globally prescriptive frameworks seek to forecast implementation issues and opportunities for improvement. Other frameworks prescribe within particular macro environmental factors, such as manufacturing process type, company size, business strategy, and specific industry type. They assume that particular macro environmental factors are the major influences upon the opportunities for improvement and the issues affecting JIT implementation.

3.5.1 Globally Prescriptive Implementation Frameworks

Several global prescriptive implementation frameworks have been proposed. These include two identified from application surveys, each involving two phases of JIT implementation, Table 3.3. However, in a third survey Im, and Lee (1989) did not identify a global pattern of implementation in their survey of 33 US firms.

Survey	Region	Stage One Implementation	Stage Two Implementation
Billesbach, Harrison, and Croom-Morgan (1991)	UK, USA	Inventory reduction, quality control measures, supplier involvement	Plant layout, detailed cross training, performance measurement changes
Bartezzaghi, Turco, and Spina (1992)	Italy	The product-process scope	Job organisation, production management, supplier relationships

Table 3.3: Globally prescriptive frameworks for JIT implementation from application surveys

According to Monden (1994: 328-329), the implementation of the Toyota Production System should follow the steps of: 5S/housekeeping (ie. organisation, orderliness, cleaning, cleanliness, and discipline (Ohno 1988b: 117-119)); layout improvement and multifunctional workers to realise one-piece production and line balancing; small lot size production and setup reduction; standard operations; smoothed production; autonomation (jidoka); and kanban/pull control systems.

A three phase implementation framework was proposed and demonstrated, with a conceptual worked example, by Miltenburg, and Wijngaard (1991). The framework required that the parts manufactured in the production system should: be standard and have regular usage; have short raw material leadtimes; have all operations completed in the plant; and have short purchased item leadtimes. Other parts remain under the current system. The three phases constitute the following systems:

1 - two-bin system. Inventory is stored at the point of use. Once working, the order point and quantities are reduced, problems are identified, and changes made;

2 - kanban JIT production control system. Kanban systems are used with a visual production control board. Once stable, the number of kanban cards and their batch sizes are reduced;

3 - continuous flow JIT production system. Layout is changed to form a continuous flow production system. The number of kanban cards and their batch sizes are reduced further.

Shingo (1989: 223) presented a framework for the introduction of the Toyota Production System over the course of twelve months at the end of his discussion of the features of the Toyota Production System, Figure 3.1.

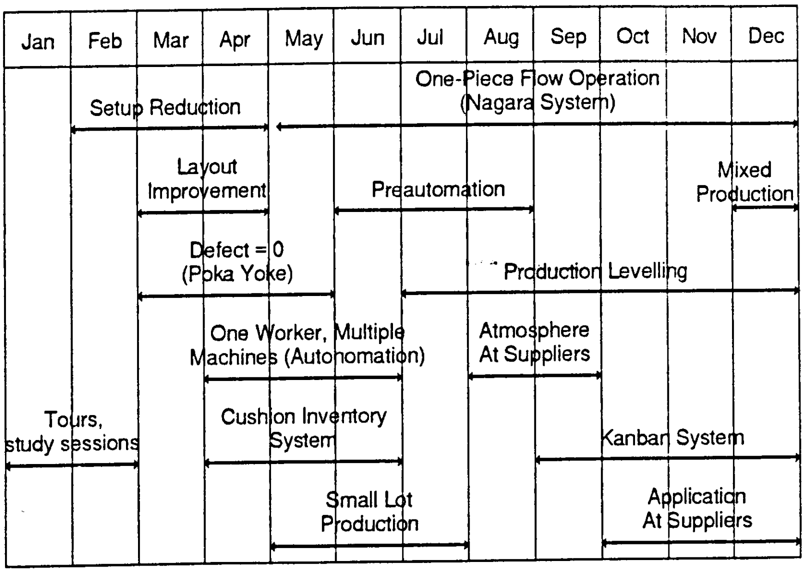

Figure 3.1: Framework for the introduction of the Toyota Production System (Shingo 1989: 223)

A five phase cyclical framework was presented by Willis, and Suter (1989):

1 - mindset. Education to provide awareness of JIT manufacturing and gain commitment from people throughout the organisation;
2 - motion. Introduction of workplace organisation, visual control, cleanliness, and preventive maintenance into operations;
3 - movement. Simplification of the production process using cellular manufacturing/Group Technology and levelled and pulled production;
4 - materials. Buffer inventory reduction, vendor relations, and quality at source;
5 - momentum. Continuous revisiting of previous stages.

O'Grady (1988: 53-112) developed a framework based on observation of JIT implementations in a number of western countries. It consists of five phases, Figure 3.2. These are:

1 - getting the ball rolling. Key people and top management are informed of the JIT philosophy, necessary steps, likely costs, and benefits. A decision to accept JIT gives authority to make changes. A project team and pilot plant are identified;
2 - education. All people associated with a JIT manufacturing system receive initial and ongoing education;
3 - process improvements. The three waste elimination techniques of setup reduction, Total Productive Maintenance, and layout improvement are used;
4 - control improvements. Pull/kanban systems are used to simplify control, and

quality at source is pursued;

5 - vendor/customer links. Single sourcing, long term contracts, minimised documentation, improved quality, reduced order quantities, and reduced leadtimes with local suppliers are pursued. Customer links are improved to ease planning problems.

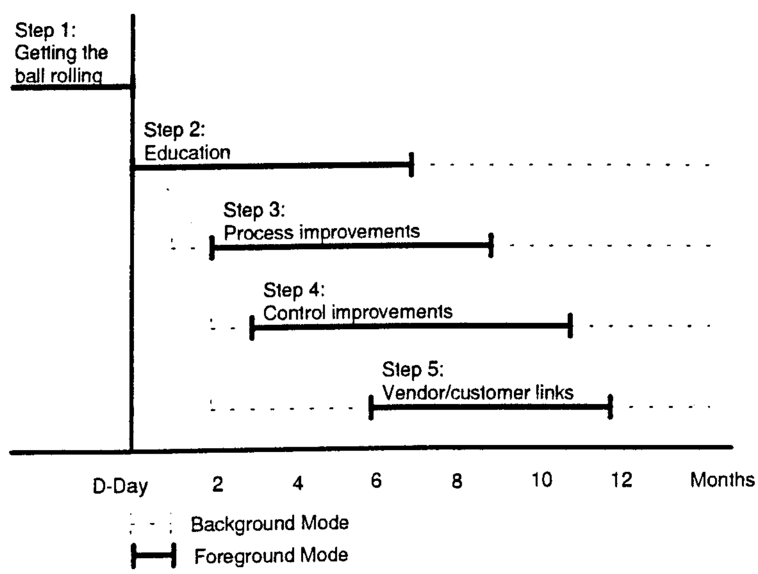

Figure 3.2: O'Grady's "proven path" implementation framework (O'Grady 1988: 118)

Sepehri (1986: 322) suggested that the implementation of JIT manufacturing may occur in four consecutive phases:

1 - conceptualisation. Learning, devising strategy, planning, experimenting, and developing confidence;

2 - preparation. Revising the plant, reducing setup times, improving process capability, and improving plant housekeeping to a point where the conversion to a pull system is not impossible;

3 - conversion. Changing from whatever method of material control now prevails to a pull system for the entire plant;

4 - consolidation and continued improvement. After the plant is operating basically by a pull system, much further improvement is possible, and the system can be the basis for evolving into full automation by whatever technological means seem feasible.

However, Sepehri added that a real JIT implementation may not be performed in such a systematic method.

These frameworks differ significantly in their guidance offered to managers pursuing the implementation of JIT manufacturing in terms of:

- the support levers and waste elimination techniques identified;
- the sequence and scheduling of activities;
- the timing of the process of JIT implementation, with most not specifying timescales.

3.5.2 Implementation Frameworks For Specific Manufacturing Process Types

Despite Im's (1989) questions, prescriptive frameworks have not been widely developed for specific manufacturing process types. Kelleher (1986) identified specific differences between job shop and flow line manufacturing organisations, such as routing sequences, which affect the use of particular waste elimination techniques, including kanban/pull control systems. White (1993) identified some differences between job shop and other process types. This suggested that greater use of multiskilled people would be made in JIT implementation in job shops. Differences between job shop and flow line manufacturing organisations would cause the process of JIT implementation to differ for each of the manufacturing process types. A demonstration of this came from Spurgeon (1984) who presented two cases of JIT implementation from the same company. One case was a job shop and the other a flow line/shop, and each was shown to have followed highly dissimilar approaches to the process of JIT implementation.

Schonberger (1984) suggested that small job shops already use cellular manufacturing and that they should pursue setup reduction, machine maintenance, TQM, and competitive analysis of product and process development. Differences resulting from the manufacturing process type were demonstrated by Voss and Harrison (1987), and Harrison (1992: 232). Flow based manufacturing systems, such as in process industries, were considered as having a large proportion of the elements of JIT in place, but could usually benefit from the adoption of selected techniques such as JIT purchasing, TPM, and setup reduction. Job shops were not suitable for the flow elements of JIT, but could benefit from selected JIT techniques such as setup time reduction, TQM, and workforce flexibility.

As shown earlier, Celley et al (1986), and Ahmed, Tunc, and Montagno (1991) identified that the level of JIT implementation does not seem to be influenced by the manufacturing process type. However, specific manufacturing process types have been shown to influence the process of JIT implementation. Some guidance has been offered for specific manufacturing process types, however, detailed frameworks focused on specific manufacturing process types have not been clearly presented.

3.5.3 Implementation Frameworks For Specific Company Sizes

Golhar, Stamm and Smith (1990) demonstrated that small firms (<500 people) had been successful in the implementation of JIT, and that business size related issues which influenced the process of JIT implementation included supplier and customer relationships and securing capital. This supported earlier research of Finch and Cox (1986) who examined the feasibility of JIT waste elimination techniques in small firms. They concluded that implementation issues related to business size created difficulties for JIT purchasing, and for uniform workload to allow levelled production.

In the case of large firms, Fielder, Galletly and Bicheno (1993) suggested that identifying precise recommendations for big companies is impossible as they are too heterogenous. However, as was shown above, Novitsky (1985) reviewed the introduction of JIT manufacturing in a consumer goods division of Phillips, and identified a single structure to take advantage of the learning curve of repeated JIT implementation across a large company.

It was shown in chapter two that the effect of company size on the level of JIT implementation is unclear. Whilst is has been seen that company size influences a number of waste elimination techniques, support levers, and implementation issues, and hence the process of JIT implementation, those affected are a minor subset of the large and diverse range of waste elimination techniques, support levers, and implementation issues to be considered throughout the process of JIT implementation. Therefore, consideration of company size related issues is important in the process of JIT implementation, but in isolation can only partially determine the selection and use of waste elimination techniques and support levers, and the presence and significance of implementation issues.

3.5.4 Implementation Frameworks For Specific Business Strategies

Norris (1992) investigated prescriptive frameworks for specific business strategies.

This sought to identify a priority for waste elimination techniques for each of the strategies of inventory reduction, quality improvement, and productivity improvement. However, the results were based on a small application survey, considered a narrow range of waste elimination techniques and no support levers, and identified only partial support for one strategy. Voss and Harrison (1987) also noted that business strategy could be related to the capabilities of JIT manufacturing.

Whilst some researchers suggest that business strategy, as a component of managerial policy within the specific manufacturing context, can influence the direction taken during the process of JIT implementation, this area has not been widely researched.

3.5.5 Implementation Frameworks For Specific Industry Types

Lee (1992) suggested that JIT implementation would be affected by industry type. Im and Lee (1989) identified some guidelines for computer, electronic, automotive, and machinery industries for groups of waste elimination techniques and support levers. This was based on only eleven cases across four industry types, considered a narrow range of waste elimination techniques and support levers, and identified only partial similarity between the approaches within industry types.

Vora, Saraph and Petersen (1990) studied the JIT implementation process in fourteen US electronics companies. They concluded that each case defined the scope of JIT manufacturing and the process of JIT implementation to suit its own unique competitive and internal conditions. Keller and Kazazi (1993) presented implementations within the same industry (automotive) which were highly different. Hum, and Ng (1995) studied the implementation plans of companies in Singapore and found that even companies in the same industry pursued JIT implementation very differently.

Industry type has been shown in chapter two to influence the level of the use of JIT manufacturing in some cases (eg. automotive and electronics). This could be a consequence of the industrial mechanisms, also reviewed in chapter two, which drove the spread of JIT manufacturing across the industrialised world. However, a common conclusion of Vora, Saraph and Petersen, and Keller and Kazazi is that industry type does not determine the process of JIT implementation.

3.6 Review of Prescriptive Guidelines

Many prescriptive guidelines on how to begin the process of JIT implementation have been proposed in application surveys, case studies, simulations, literature surveys, and conceptual discussions. Many different activities are identified as important first steps. The scope of issues identified are broad, but generally divide under preparatory, human and organisational, and engineering headings.

With regard to preparation for implementation, Sohal, Ramsay and Samson (1993) proposed that for companies to introduce JIT successfully they must identify their strategy, their basis of competition, and undergo preparatory planning. Before making changes to the manufacturing system, Johnson (1994) stated that the first step is to detect how much change is necessary and in what parts of the business. The mechanism of benchmarking was suggested. Andrew (1984) also identified the benefit from benchmarking factory operations to identify improvement opportunities at the start of JIT implementation.

Human and organisational issues are widely identified as important steps to JIT implementation by researchers. Oliver (1991) discussed the requirement for multiskilling for increased flexibility of the human resources to counter the reduction in inventory levels in a JIT manufacturing system. This was identified by Voss and Harrison (1987) who noted that as flexibility in the organisation is a long and difficult road, companies adopting JIT must consider how they will make their organisations more flexible from the very start. Macilwain (1988) presented the thoughts of the Scottish JIT Club who also proposed that JIT must start with the development of the people in the organisation. Wilkinson and Oliver (1990) argue that most companies which have adopted JIT in the West have demonstrated that existing organisational structures and cultures pose some of the most difficult problems in successful JIT implementation. Associated factors such as awareness and ongoing training programs, the assignment of increased responsibility to operators and improved communication, together with involvement in decision making, were identified by Sohal, Ramsay, and Samson (1993) as prerequisites for the employee cooperation and understanding vital to successful implementation of JIT manufacturing. Billesbach (1991) recommended that JIT should be endorsed in corporate strategy and communicated to all, all should be trained and educated in JIT principles, and time provided for operators to become involved in the improvement process.

There are a range of authors who have identified particular engineering activities as important first steps of JIT implementation. There is little agreement between them. Implementation should start with work in process reduction including reduction of the safety time margins used by material planning systems according to Cheng (1988) as many companies have a much wider margin than is necessary to prevent stoppages caused by late deliveries. Incremental improvements by reducing inventories, eliminating waste, and exposing problems for solution were recommended as the first steps toward JIT purchasing by Ansari (1986), whilst Chapman (1989) suggested that the implementing firm should begin JIT purchasing by providing supplier education and unambiguous communication of intentions to prevent counterproductive supplier responses. The implementing firm should then work on the elements of leadtime and lot size that could allow delivery of small lots of high quality material without excessive amounts of buffer inventory.

Other engineering activities are identified as first steps. The introduction of the Toyota Production System is started, according to Monden (1994: 328-329), with the application of 5S housekeeping activities. This supports Sepehri (1986: 318). Billesbach (1991) highlighted the need for streamlining production flows, the adoption of cellular manufacturing and product families, simplification of material handling, and arranging equipment in flow lines. Arogyaswamy, and Simmons (1991) recommended that layout improvement and setup reduction should be pursued first, followed by pull control and scheduling changes. However, Gilbert (1990) argued that "companies may well be best served by starting in-house programs of lot size reductions and quick setup", and that elements such as buffer stock removal, group technology, overlapped scheduling, consistency in the master production schedule, standardisation of component items, and plant-wide involvement in work improvement projects should come later. Similar approaches were raised by Keller, and Kazazi (1993) who noted that academics and practitioners cite setup time and leadtime reductions as essential starting points. However, they concluded that the first action in the implementation of JIT was the introduction of TQM. Crawford, Blackstone and Cox (1988) proposed an initial focus on TQM and preventive maintenance to ensure the ability to maintain deliveries. Contrary to these, Bicheno (1991: 109) stated "JIT can start with imperfect quality - otherwise it would never start. JIT is the partner of quality improvement." According to Harrison (1992: 3) there seems to be no reason why development of TQM should precede JIT. Also, McTighe (1991) recommended that TPM should be employed after achieving JIT-type production flow. In an office environment, Johnson (1994) identified the first step as finding teams or cells that when brought together contain all the skills and resources necessary to complete whole processes.

The steps above were generally identified from simulation by Ritzman, King, and Krajewski (1984) as "levers for boosting performance". Their recommendations were: reducing lot sizes and setup times; improving process yields; smoothing capacity; increasing worker flexibility; improving product structure towards a pyramid shape with fewer final assemblies, more components at lower levels, and fewer BOM levels. Voss, and Harrison (1987) summarised the objectives of the first steps as achieving simplicity, flow, quality, and fast setup.

In addition to no consensus being evident between the different frameworks for JIT implementation, there is little agreement regarding guidelines on the first steps of JIT implementation. Guidelines propose that many different activities are required simultaneously at the start. The requirement for furious activity involving numerous different waste elimination techniques and support levers at the start of the JIT implementation process is not guidance of a practical nature for manufacturing companies with limited experience of JIT manufacturing in practice, restricted resources available to develop the manufacturing system, and a need to maintain production and deliveries to customers as the principle function of the manufacturing system during its development.

3.7 Review of Tailored Implementation Frameworks

Tailored implementation frameworks seek to allow users to shape the guidance according to the specific manufacturing context. The frameworks are evaluated later in the chapter to appraise their ability to meet the objective of successfully directing the transformation to JIT manufacturing.

Bicheno (1991: 13-14) identified two groups of waste elimination techniques and support levers, called stage one and stage two, Table 3.4. Stage one practices are considered to be applicable in all operations, and prepare the plant for flow, flexibility, short leadtime, and high quality. Stage two practices are understood to be less applicable where volumes are low or variety is high. They build on those of stage one and achieve short leadtime and reduce waste. It is not the intention that all stage one practices should be implemented before starting stage two. Instead, actions in stage one allow actions in stage two which then allow further action in stage one. This cyclical process is then repeated, ad infinitum. Every time an improvement is made then further development become possible in other areas, and these should be identified and pursued.

Stage one	Focus; Design; Maintenance (Total Productive Maintenance); Quality (TQM); Small Machines; Layout and Group Technology; Setup Reduction; People Preparation.
Stage two	Total People Involvement; Visibility; Process Data Collection; Enforced Improvement; Flow Scheduling; Inventory Control; Buffer and Lot Size Reduction; Supplier and Customer Partnerships.

Table 3.4: Stage one and stage two JIT manufacturing practices (Bicheno 1991: 14)

The framework for JIT implementation begins with the identification of key performance measures, setting of targets, and recording initial measures. A detailed plan is not considered worthwhile as JIT implementation is viewed as an ongoing process. Rather, the plan is used to identify the broad sequence of actions to be taken (Bicheno 1991: 84) and would be subject to frequent revision. A project plan for the implementation of JIT was not developed as the exact relationships will depend on the situation (Bicheno 1991: 101).

As identified earlier, there are many possible paths for JIT implementation. One example is improved maintenance, giving reduced buffer stocks, allowing improved layout, permitting better visibility, facilitating improved quality, and so on (Bicheno 1987). The process of JIT implementation was expected to be affected by strategic and contextual issues such as competitive pressures, industrial relations, workforce skills, product type and volumes, size, and state of demand (Bicheno 1991: 11).

The potential for basing guidelines for the selection of waste elimination techniques and support levers according to the characteristics of volume, unit contribution, product life remaining, supply time pressure, and family variety was raised. However, it was noted that this would require a large volume of analysis and would probably be self-contradictory in places (Bicheno 1991: 55-57). This suggests that this approach would be time consuming and involve significant risk of failure.

This framework did not identify which waste elimination techniques and support levers of JIT manufacturing should be applied where in the manufacturing system and when in the process of implementation. Also, it did not provide a practical mechanism to allow a user to identify which waste elimination techniques should be applied where in the manufacturing system and when in the process of implementation. Hence, no solution to the JIT implementation dilemma was achieved.

Voss (1988) advocated a framework based on the earlier work of Bicheno (1987) where two groups of waste elimination techniques are identified. However, this followed a serial process of JIT implementation where the first group was completed before the second group was started. This suffered from the same problems as the work of Bicheno (1991).

3.8 Evaluation Of JIT Implementation Processes

Prescriptive implementation frameworks and guidelines identify specific waste elimination techniques and support levers together with a schedule for their use. A forecast of the presence and significance of implementation issues is assumed and this determines the selection and sequence of waste elimination techniques and support levers. This has the advantages of being fast to introduce, as little analysis is required prior to implementation, and also requires less in-house expertise as a the guidance is presented by the framework. However, every manufacturing site is unique, and no blanket prescription will apply equally to them all (Ritzman, King, and Krajewski 1984). This can be demonstrated by adapting the river and rocks analogy presented by Mather (1988: 26), Hay (1988: 31-33) and Suzaki (1993: 163), Figure 3.3a). The manufacturing system or company is represented by the ship floating on water whose depth represents the level of inventory. Implementation issues in the manufacturing system, such as those in Table 3.1, appear as rocks whose height is proportional to their significance. These determine the depth of water required to prevent the manufacturing system being damaged by collision with the issues, that is, to prevent the ship hitting the rocks. In order for the manufacturing system to successfully function with lower levels of inventory the significance of the implementation issues, and hence the height of the rocks, must be diminished and the depth of water reduced. This is achieved by the elimination of waste. This process is shown in Figure 3.3b) and c).

In effect, prescriptive implementation frameworks and guidelines forecast the height of each rock. Such an approach can be applied to successfully reduce waste and allow the manufacturing system to function correctly with lower levels of inventory. An example case, shown in Figure 3.4, demonstrates long setup times preventing the reduction of inventory (a). Successful application of a setup reduction waste elimination technique results in shorter setup times, the issue of long setup times diminishes, and the level of inventory can be successfully lowered (b). The manufacturing company can operate with lower levels of inventory (c) and as the issue of long setup times diminishes further other issues, such as supplier delivery or rejects in this example, prevent further successful reduction of inventory. In this instance, the forecasted significance of the implementation issues was correct.

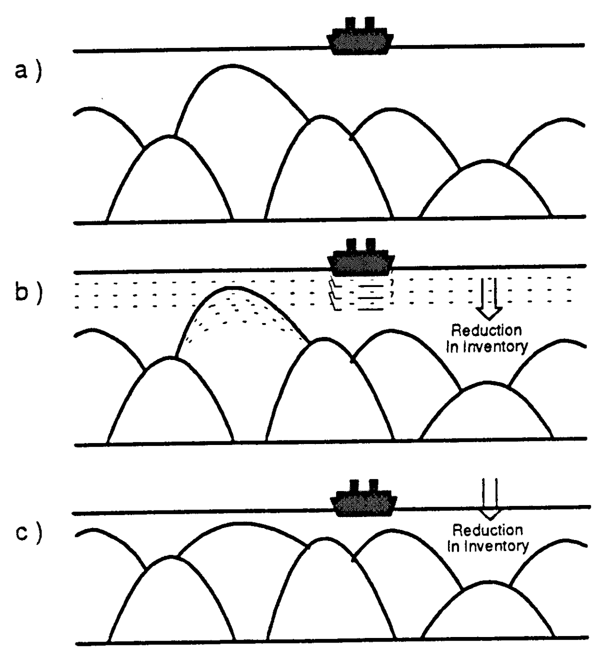

Figure 3.3: The river and rocks analogy (Mather 1988: 26, and Suzaki 1993: 163)

The same prescriptive implementation framework and guidelines can be shown to be unsuccessful in a second example case, shown in Figure 3.5. In this instance, the issue of rejects is preventing the successful reduction of inventory (a). The prescriptive implementation process again seeks to reduce setup times, and the significance and size of the issue of long setup times is reduced (b). However, any attempt to reduce the level of inventory as a result of the changes made to the manufacturing system will prevent successful operation of the manufacturing system (c). In this case, the forecasted significance of the implementation issues was incorrect.

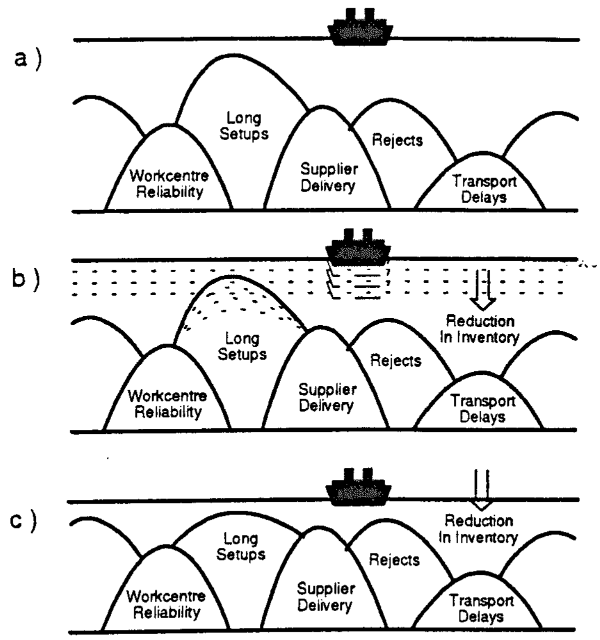

Figure 3.4: Successful example of the use of a prescriptive JIT implementation framework

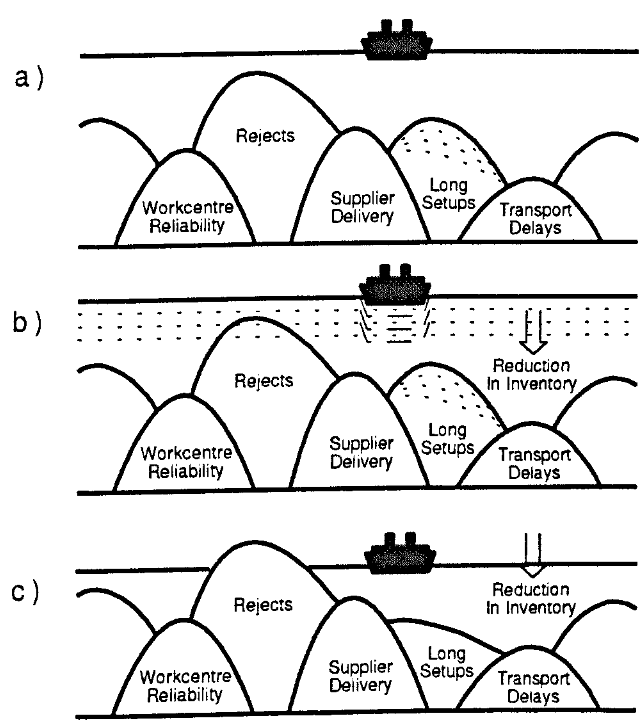

Figure 3.5: Unsuccessful example of the use of a prescriptive JIT implementation framework

There are many implementation issues involved that are specific to each case.

Table 3.1. It is unlikely that a process of forecasting the significance of implementation issues would work successfully for long, if at all. The presence of implementation issues and opportunities for improvement will be different from case to case, even within the same country, industry, company, and factory (Hallihan, Williams, and Sackett 1995), as will be shown in chapter four, "The Chadderton Industrial Cases".

A manager considering implementation of JIT should not attempt to duplicate another facility's implementation (Crawford, and Cox 1991). This would risk the failure of the implementation as inappropriate waste elimination techniques and support levers may be pursued. Hence, prescriptive frameworks present an increased risk of failure as implementation issues may not be correctly forecasted.

Finch, and Cox (1986) asked what would be wrong with a factory having, for example, short machine setup times and a total productive maintenance program, despite an inability to pursue other waste elimination techniques and support levers? The ability to gain advantage from specific waste elimination techniques and support levers whilst others are not available was stressed by Voss, and Harrison (1987). Hence, JIT manufacturing may be pursued and advantage gained by the application of waste elimination techniques and support levers on a case by case basis. Specific examples of six companies were raised by Sohal, Ramsay, and Samson (1993) who indicated that although certain waste elimination techniques and support levers of JIT were inappropriate, it did not preclude the application of others resulting in successful JIT implementation. A prescriptive implementation process would either have forced these cases into the situation of Figure 3.5 c), and hence risked failure of the implementation, or prevented the identification of opportunities for improvement and not resulted in successful implementation. These can be considered as additional shortcomings of prescriptive frameworks. It also demonstrates that there is no one best method of implementation. Hall (1982) presented a case from Kawasaki, Lincoln where due to a particular implementation issue, rejects, the implementation of JIT in a specific component manufacturing area was tailored, and hence differed from the practices elsewhere in the plant. Prescriptive frameworks and guidelines would not consider the local variation in implementation issues and risk the failure of the implementation, or ignore openings for improvement and pursue non-productive activities whilst gaining little benefit. Schonberger (1986: 53) supported this and proposed that not all waste elimination techniques and support levers are usable in every case, but in every case some are useful.

According to Finch, and Cox (1986), understanding why particular waste elimination techniques and support levers are used instead of others, and what is applicable and what is not, is required to achieve a mature JIT implementation. This understanding is blocked when a prescriptive framework is employed, as they present only what is to be done, not why it is to be done.

Advocates of tailored frameworks and guidelines argue that to maximise the benefits and minimise the risk of failure, a company should start with waste elimination techniques and support levers that are most suited to its business. For this, it is necessary to determine which techniques are suitable for implementation by a given firm (Lee 1992). The characteristics of the manufacturing system should be evaluated to determine the implementation plan (Lockamy, and Cox 1991). Hence, JIT should be examined and modified to account for local factors and company needs (Finch, and Cox 1986; Sohal, Ramsay, and Samson 1993). Ultimately, the individual plant and its specific conditions will determine the appropriate waste elimination techniques and support levers that should be applied. An understanding of what is applicable and what is not is necessary (Finch, and Cox 1986). Hence, tailored frameworks seek to reduce the risk of failure as implementation issues are identified instead of being forecasted. Waste elimination techniques and support levers are then selected as appropriate. Also, higher performance may be achieved as only those waste elimination techniques and support levers that offer significant improvement are selected and pursued ahead of those that may offer lower returns. The process of selecting waste elimination techniques and support levers imparts an understanding of "know-why" in the company and this will enable further progress in the future.

The selection of waste elimination techniques and support levers requires detailed knowledge to be held by the local management, or for it to be imported into the manufacturing company. The time spent analysing and selecting the waste elimination techniques and support levers reduces the speed of the initial stages of the implementation.

The main shortcoming of current tailored frameworks and guidelines is that they tend to lead up to the JIT implementation dilemma without providing a solution. This was shown in the work of Bicheno (1991) where no implementation plan was developed and the mechanism suggested to identify such a plan was acknowledged as highly time consuming and potentially self-contradictory. This identifies the need for a practical mechanism to evaluate waste elimination techniques and support levers within the specific manufacturing context such that appropriate selections can be made for each instance.

3.9 Conclusions

Numerous and diverse issues were highlighted as important throughout JIT implementation. None were shown to be dominant, and their interrelationships were shown to be complex and unclear. The significance of these issues are determined according to each individual case. This, together with the large number of changes that are required to achieve a mature JIT manufacturing system, means that JIT implementation is a large and complex problem.

The difficulty of determining which waste elimination techniques and support levers should be applied, where, and when during the transformation to a mature JIT implementation was identified. This was referred to as the JIT implementation dilemma. Many researchers have presented guidance for a solution to this. However, there is no consensus regarding a preferred route to JIT implementation.

Implementation strategies provide only high level guidance, without presenting the detailed support required to direct a manager wishing to implement JIT manufacturing. Prescriptive frameworks and guidelines seek to simplify the problem of the JIT implementation dilemma by assuming, or forecasting the presence and significance of implementation issues. These have been demonstrated to exhibit significant shortcomings, including an increased risk of implementation failure. Tailored frameworks assume that the solution to the JIT implementation dilemma depends upon the manufacturing system and its context. They acknowledge that a manager considering implementing JIT manufacturing should not attempt to duplicate another facility's implementation. They do not attempt to forecast the presence or significance of implementation issues. However, the tailored frameworks proposed in literature do not present practical mechanisms with which to generate a solution to the JIT implementation dilemma. They merely lead up to it.

Hence, prescriptive approaches to the implementation of JIT manufacturing are fundamentally flawed, whilst the tailored alternatives do not currently present a practical method for the solution of the JIT implementation dilemma. This thesis will seek to identify a practical mechanism capable of identifying a tailored solution to the JIT implementation dilemma. This will be approached through the consideration and analysis of the subsequent case studies, in chapter four, and additional cases from literature.

Chapter Four

The Chadderton Industrial Cases

4.0 Introduction

This chapter presents three case studies of JIT implementation that were conducted during this research. A description of the common background to the cases is given, followed by a short sketch of each case. The results of the three cases are presented together, for clarity of comparison. Analysis of the cases then follows. The roles of each of the thirteen core waste elimination techniques of the pyramidal model of JIT manufacturing are discussed. This demonstrates the importance of two identified variables on the process of JIT implementation in each of the three cases.

4.1 JIT Manufacturing in British Aerospace Chadderton

The Kawasaki Production System (KPS) is a derivative form of JIT manufacturing developed by Kawasaki Heavy Industries (KHI) from 1976 at their Akashi plant. It was based on the Toyota Production System (TPS). This was shown in Figure 2.2. Hence, the terms KPS and JIT are treated synonymously in this text.

British Aerospace and KHI signed an agreement in 1993 under which KHI provided education, training and expertise in order to facilitate the implementation of KPS within BAe. BAe engineers received training at Kawasaki factories at Akashi and Gifu in Japan and senior KHI engineers were seconded to BAe to act as advisers.

The BAe Chadderton factory was identified as one of a small number of sites which would pioneer the implementation of KPS within BAe. Reasons for introducing JIT manufacturing within BAe are those reviewed in the first chapter regarding the increasing competitiveness of the industry. BAe Chadderton is a supplier of airliner and regional aircraft subassemblies, based in Manchester, which employs around 2,300 people. It performs component manufacturing and subassembly on a low volume, high variety, and medium to high value basis.

Two engineers from BAe Chadderton were sent to a training course hosted by KHI in Japan. During this time, senior KHI engineers, with the assistance of the researcher, evaluated areas within Chadderton to select pilot areas, evaluate current performance, and determine implementation objectives in terms of performance improvement. These objectives were to achieve 30% reductions in work in progress and leadtime, and a 30% increase in productivity. Three manufacturing areas were selected. Each of these exhibited cellular-style ownership of facilities with a defined product range. Selection was influenced by enthusiasm of local managers and the need to improve performance to secure current and future orders. All three pilots selected reported to the same senior production manager. Pilot areas also needed to closely represent the nature of work performed at BAe Chadderton, and satisfy the KHI engineers that KPS offered a means to improve their operation.

Detailed analysis of the manufacturing systems began when the two engineers returned from Japan to join the researcher. An education and training course was developed for operators, engineers, managers, and others affected by the implementation of KPS. This covered the theory of JIT manufacturing. The education and training course involved videoing the current manufacturing system, and developing improvement ideas to eliminate waste and take the first steps towards JIT manufacturing. The course immediately reinforced the education and training with hands-on practical experience for the attendees in their own working environment. These courses were repeated to increase the number of people at Chadderton with understanding of JIT manufacturing coupled with experience, and to generate improvement ideas to continue the elimination of waste in the manufacturing systems. An educational video was also made to increase the awareness of KPS across Chadderton (which was later translated into Japanese for use by KHI in Japan).

A small working group was attached to each case. These consisted of the production managers responsible for the areas, engineers, and operators. Members of the working groups would hold weekly review meetings with a senior production manager, and monthly reviews with a site steering group, which consisted of the senior managers of all departments at BAe Chadderton. Implementation plans, which detailed the activities for a period of ten weeks, were the principal document used for project management.

Each of the three cases demonstrate the benefits from the implementation of JIT manufacturing in commercial aircraft manufacturing over a period of five months, and provide information regarding JIT implementation. The three cases used different JIT waste elimination techniques for various reasons, chiefly to overcome problems within the manufacturing systems as they were prior to and during the implementation of KPS. The manufacturing systems selected were the facilities for rib assemblies, buttstraps, and titanium undercarriage assemblies (TUAs). BAe Chadderton's intention was to implement KPS across the whole site. Later cases of KPS implementation included the facilities for stringers, spars, stretch-formed components, and Avro Regional Jet machined parts. Sketches of the three cases are presented below.

4.2 Case One: Rib Assemblies

A rib assembly consists of one major aluminium alloy machined component assembled with a number of brackets and standard parts. One aircraft set includes 20 rib assemblies, with around 20 aircraft sets per year. The main equipment in the manufacturing cell consists of one long bed three-spindle NC mill, one mill, one drill, an assembly fitting area, and NC inspection facilities. Centralised treatment facilities are used. An aluminium billet would be NC milled, prior to post-NC machining and inspection. The assembly would then be made from the billet, brackets and standard parts and passed into final NC inspection.

The manufacturing cell was worked by twenty direct operators over a twenty four hour, six days a week shift arrangement. These included skilled machine operators and fitters. One production engineer and supervisor were assigned to the cell. Through a local manufacturing manager, this cell reported to the senior Airbus production manager at Chadderton. A chronic problem for this cell was the inability to deliver to customer demand for assemblies, despite having high levels of finished goods inventory. This was a demonstration of the waste of overproduction, related to the large production batch sizes, suited to the three-spindle equipment.

The rib manufacturing system was enhanced by:

- a batch size reduction from three to one as a result of gaining sufficient capacity by reducing setup times from 220 minutes to 10 minutes. Levels of work in progress and leadtimes were reduced as large batches of finished assemblies were weaned from the manufacturing system. Interoperation queues shortened. Changes to setup activities reduced the motion and waiting of operators which improved productivity. The reduction in setup time is shown in Figure 4.1;
- relocating the machines and ancillary equipment to follow the process flow. This reduced the transport of work in progress, motion of operators, queues, waiting time, and leadtimes.
- process modifications, including reprogramming and changes to cutters, which improved quality and reduced the processing time. The volume of material scrapped or forced to wait for concession approval or reworking was reduced. This improved the level of work in progress, leadtime, and productivity;
- other improvements resulted from operator quality approval improving product quality at source, and training towards multiskilling to allow operators to use all cell machines. These reduced queues, leadtime, and waiting time, further improving towards the work in progress, leadtime, and productivity objectives.

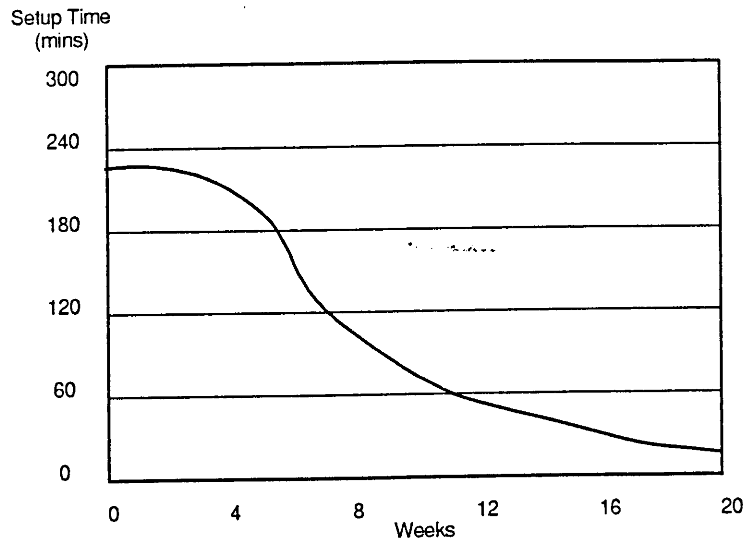

Figure 4.1: Reduction in setup time - Rib Assemblies

4.3 Case Two: Buttstraps

A buttstrap is a complex manually machined reinforcing plate manufactured from an aluminium alloy billet. Their manufacture involves eighteen major operations with an accumulated operation run time of around 200 hours, equivalent to three shift weeks. One aircraft set includes 10 part numbers, with around 20 aircraft sets per year. The main equipment in the manufacturing cell consists of five milling machines, one bandsaw, one drill, two profilers, a fitting area, and inspection facilities. Centralised treatment facilities and a process-based stretch forming operation are required. Aluminium billets were delivered to the cell. These would be milled to size, and a cross-section then machined. The machined billet would be transported to treatments where it would be stretch formed to match the three dimensional contours of the aircraft wing. After being returned to the cell, post stretch forming machining and fitting were then used to provide the correct profile and detail dimensions. The machined complete component would then be passed into final treatments and inspection.

The manufacturing cell was worked by sixteen direct operators over a twenty hour, four and a half day shift arrangement. These included skilled and semi-skilled machine operators and skilled fitters. A production engineer was shared with another cell, and a supervisor was assigned to the cell. Through a local manufacturing manager, this cell reported to the senior Airbus production manager at Chadderton. A chronic problem for this cell was the inability to deliver to customer demand. Great difficulty was encountered in managing the long sequence of time-consuming operations to meet the delivery requirements, as bottleneck facilities became committed to the completion of a batch of one product whilst other products in demand were forced to wait for extended periods of time.

Main improvements resulted from:

- a combination of visual and pull control mechanisms reduced the level of work in progress from 55 parts to around 44 parts by controlling the number of batches in circulation. This reduced leadtime;
- setup reduction at bottleneck facilities generated sufficient capacity to allow a reduction in machining batch sizes from two to one. This reduced work in progress to around 28 parts. Leadtime was further reduced. Changes to setup activities reduced motion and waiting of operators, improving productivity;
- improved levelling of production, mainly at the process-based stretch forming operation from batches of twelve to four, reduced work in progress to around 20 parts. Queuing, and leadtimes was reduced;
- other improvements included multiskilling and improvements to the process to condense operations and improve quality. Condensing of operations reduced queues and work in progress, and increased productivity by reducing motion and waiting of operators. Quality improvement reduced sources of scrap, and queues for concession approval, giving further work in progress reduction and productivity improvement.

Work in progress reduction from these techniques is shown in Figure 4.2.

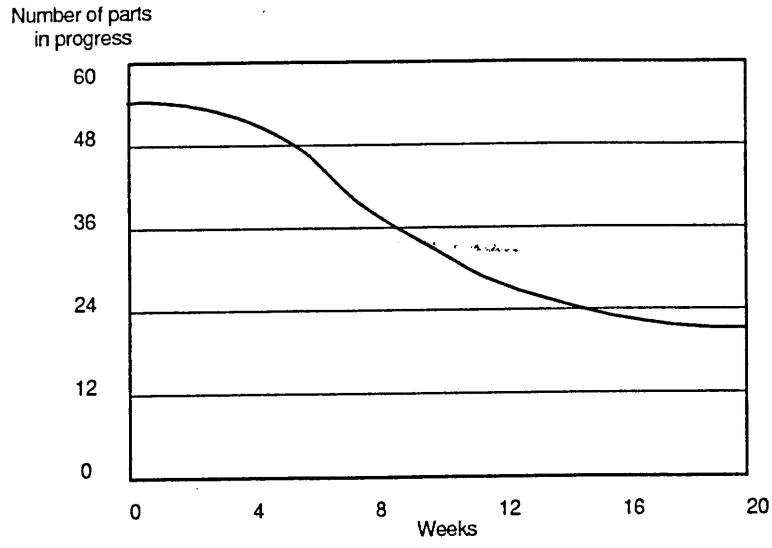

Figure 4.2: Reduction in work in progress - Buttstraps

4.4 Case Three: Titanium Undercarriage Assemblies (TUAs)

This facility produces a collection of twelve assemblies. Each assembly consists of one major component, machined from a titanium alloy forging, assembled with bushes and standard parts. One aircraft set consists of 2 to 6 assemblies, with between 6 to 45 aircraft sets per year. Annual requirements total around 350 assemblies. The main equipment in the manufacturing cell includes two three-spindle NC mills, two vertical mills, one vertical lathe, one drill, one jigborer, an assembly fitting area, and NC inspection. Centralised treatment facilities are used. A titanium alloy forging would undergo conventional pre-NC machining, followed by roughing NC machining. Centralised treatments were then used for stress relieving. Finishing NC machining would then be followed by finishing operations by fitters, and inspection. NC machining cycles could extend to eighty hours. Further treatments would then be used. On return to the cell, post NC machining, such as jig boring, and assembly with bushes and standard parts would produce completed assemblies. These would be passed into final inspection and treatments.

The manufacturing cell was worked by twenty five direct operators over a twenty four hour, six days a week shift arrangement. These included skilled and semi-skilled machine operators, and skilled fitters. A production engineer was shared with another cell, and a supervisor was assigned to the cell. Through a local manufacturing manager, this cell reported to the senior Airbus production manager at Chadderton. Problems with this manufacturing cell included low delivery reliability, stiff cost competition, and control of raw material forgings and work in progress.

The most significant improvements in the performance resulted from:

- layout improvement which eliminated bottlenecks through the duplication of facilities. Material flow was improved. This reduced queues, work in progress and leadtime. Transport and motion were reduced, increasing productivity;
- a substantial improvement in housekeeping or workplace organisation, assisted by the layout improvement, and the introduction of visual and pull control mechanisms closely controlled the number of batches in progress. This reduced work in progress and leadtimes. Detailed standard operation sheets reduced variation in the setup and processing times, and increased productivity;
- mixed and levelled production ensured that supply closely followed demand and this further reduced the work in progress and leadtimes. Mixed production was particularly important in this case to match the supply to the different demand rates for the twelve assemblies manufactured;
- setup reduction and process improvement increased productivity and allowed a small amount of batch size reduction. Discussion with forging suppliers presented an opportunity to reduce the level of raw material held by providing more topical and accurate information regarding requirements to the suppliers.

4.5 Summary - Cases and Results

The JIT manufacturing waste elimination techniques which provided the improvements in manufacturing system performance in the cases of rib assemblies, buttstraps, and titanium undercarriage assemblies are summarised, Table 4.1.

	Rib Assemblies	Buttstraps	TUAs
First	Setup reduction	Visual and pull control mechanisms	Layout improvement
Second	Layout improvement	Setup reduction	Visual and pull control mechanisms
Third	Quality improvement/ process improvement	Levelled production	Mixed and levelled production
Other	Quality at source Multiskilling	Multiskilling Quality at source	Setup reduction JIT purchasing/delivery

Table 4.1: Summary of waste elimination techniques used in BAe Chadderton pilot cases

A summary of the results achieved after a period of five months in the three cases discussed is shown in Table 4.2. This table compares changes in five measures including the objectives of work in progress reduction, leadtime reduction and productivity improvement. The objective of 30% improvement was generally exceeded. The nature of the changes made as a part of the introduction of JIT manufacturing waste elimination techniques means that many improvements are ongoing and will continue. One example of this is the work in progress and leadtime reduction for ribs. The changes already made and those in progress are expected to give work in progress of £48k (85% reduction) and a leadtime of less than five weeks (75% reduction) once fully implemented. Another example is the buttstraps where work in progress of £80k (51% reduction) and leadtime of less that seven weeks (62% reduction) is expected.

The results from these cases, and of subsequent KPS implementations in other areas have secured BAe Chadderton the reputation of the fastest improving commercial aircraft manufactory within BAe. Its achievements have been noted within Japan by the Kawasaki Heavy Industries board and aerospace division. News of the progress at BAe Chadderton has also been reported in Japan by Nikkei Business Publishing (Nikkei 1995 in Japanese).

	Rib Assemblies	Buttstraps	TUAs
Setup Reduction (minutes and %)	220 to 10 mins 95%	55 to 25 mins 55%	50 to 27 mins 46%
Batch Size Reduction (parts and %)	3 to 1 66%	2 to 1 50%	some of 6 to 3 14%
Work In Progress Reduction (£ and %)	£325k to £125k 61%	£162k to £88k 46%	£611k to £375k 38%
Leadtime Reduction (weeks and %)	19 to 12 weeks 36%	18 to 10 weeks 44%	18 to 5 weeks 72%
Labour Productivity Improvement (%)	30%	12%	29%

Table 4.2: Summary of results achieved in KPS implementations at BAe Chadderton

The magnitude of the improvements achieved, those expected, and their timescale demonstrates the significance of the effect that JIT manufacturing can exercise on the commercial aircraft manufacturing industry. Throughout the period of five months:

- the combined inventory reductions across the three cases was in excess £0.5M, giving a mean reduction of 48% and a weighted overall reduction of 46%;
- leadtimes were reduced by a mean of 51% and between 36% and 72%;
- productivity was raised by a mean of 23% and between 12% and 30%.

The benefits of repeating and increasing these improvements can be roughly illustrated by the consideration of the sales of $41,323M in 1993 across the commercial aircraft manufacturing industry. More specifically, for Airbus Industrie's sales of $8,300M in 1993, and British Aerospace's $2,368M (O'Toole, 1994b). British Aerospace achieved a stockturn of three, and pursue a labour intensive nature of the manufacture of commercial aircraft, similar to that of other manufacturers. WIP reductions of the magnitude demonstrated in the cases would provide savings within British Aerospace if repeated throughout their commercial aircraft manufacturing operations of around $400M in inventory together with further savings in holding costs in the first year and each subsequent year estimated at $130M according to Williams, Williams, and Haslam (1989). Productivity improvements would contribute towards further reduced product costs and leadtime reductions would support increased flexibility in meeting customer specific demands. However, the undertaking of JIT implementation across the commercial aircraft manufacturing operations of BAe is obviously a very large and difficult task. These figures are based on the improvements achieved in the first five months of JIT implementation which were expected to increase further due to continuous improvement through the thorough elimination of waste that is pursued during the implementation of JIT manufacturing.

4.6 Discussion Of The JIT Implementation Process

Most of the products affected had been in production for more than ten years. Hence, rapid improvements in performance at the early stages of production, relating to the early stages of a learning curve, should not be applicable in these cases. All three cases of JIT implementation were successful in achieving significant change in performance (around 30% or greater) in a short period of time. Despite this, there are clear differences between the JIT implementation processes in the three cases discussed, shown in Table 4.1. They arise in terms of the waste elimination techniques used, the significance of each technique, and the sequence of their use.

Two variables were found to model the development of the solution to the JIT implementation dilemma, and hence influence the JIT implementation process, in each case. These were:

- the level of opportunity offered by each waste elimination technique for improvement of manufacturing system performance that was perceived by local managers, engineers, and operators, factory service managers and supply chain managers. In a given case, it was likely that this would be different for each waste elimination technique; some waste elimination techniques would be perceived to offer a high opportunity for improvement, whilst others would appear less advantageous;
- the measure of support from local operators/managers, factory service operators/managers, and supply chain (supplier and customer) managers for the application of each waste elimination technique. It is likely that this would be different for each waste elimination technique. Also, different waste elimination techniques would require different sources of support. For example, JIT purchasing is mainly dependent on support from supply chain managers, setup reduction is subject to local operator/manager support, and product simplification, component standardisation, and product modularisation can be reliant on factory service operators/managers.

The thirteen core waste elimination techniques are reviewed below, in the sequence of Table 2.2, to determine the effect of the level of opportunity and the measure of support at the time of implementation.

1 Multiskilling of operators had been in existence in isolated areas of BAe Chadderton prior to the implementation of KPS. Support for extending the use of multiskilling of operators was generally high throughout local and factory service areas due to an agreement within BAe Chadderton which recognised and rewarded people for improving the range of skills in which they could demonstrate competence. Support from the supply chain did not exercise a strong influence in this subject. The level of opportunity for improvement of the manufacturing system perceived by local managers was variable, even within pilot areas. Multiskilling would allow some operations to be coupled more closely, removing the interoperation queues of work in progress and reducing leadtimes. The clearest cases of this were in the rib assemblies and buttstraps facilities. The use of multiskilling was increased in these cases. This reflected the combination of strong support and high level of opportunity.

2 WIP reduction and small lot sizing attracted strong support from local, factory service and supply chain areas following the dissemination of the JIT manufacturing training course. However, the opportunity for improvement was related to other waste elimination techniques discussed below, including setup reduction, visual control, and pull control.

3 Large batches of expensive raw material forgings from the USA, France, and the UK presented a high level of opportunity for immediate improvement by using JIT purchasing for the titanium undercarriage assemblies. The level of opportunity for immediate improvement was not matched in the cases of the rib assemblies and buttstraps as they received small batches of raw material close to when it was needed and so held small quantities of raw material. Local operator/manager and supply chain (supplier) management support allowed changes that significantly reduced the stockholding of raw material forgings in exchange for more accurate information of requirements; a task helped by reduced work in progress and leadtimes.

4 Preventive maintenance was not perceived as an high opportunity for improvement by any of the cases. The Chadderton maintenance department

were actively promoting preventive maintenance and hence provided strong support for the waste elimination technique. It was not implemented in any of the cases as other waste elimination techniques which enjoyed strong support were deemed to offer greater opportunities for improvement. However, due to the support of the Chadderton maintenance department, it is likely that preventive maintenance would be pursued in the future on a case by case basis when the level of opportunity for improvement is perceived to be notably higher.

5 Setup reduction of 100% would not offer the opportunity of the reduction of batch sizes below the normal batch size of three with subsequent improvements in work in progress and leadtimes for the titanium undercarriage assemblies; all spindles of the three spindle NC mills were required to meet demand for products. However, setup reduction would generate sufficient capacity to allow the reduction in batch sizes down to one for rib assemblies and buttstraps. All cases enjoyed strong support from local operators/managers and factory support service managers. The combination of the high level of opportunity for improvement and strong support combined to enable successful implementation of setup reduction and batch size reduction in the cases of the rib assemblies and buttstraps. Although some setup reduction was pursued in the instance of the TUAs as a demonstration of the elimination of waste, it was not as intense due to the smaller opportunity for improvement available.

6 Product simplification/component standardisation/product modularisation was not implemented in any of the cases due to the low level of factory support service manager support. This was due to the high barriers to engineering change resulting from regulatory procedures in the commercial aircraft manufacturing industry. All cases, particularly the TUAs, could have taken advantage of high opportunity for improvement to eliminate wastes of processing time and rejects and improve towards all of the objectives. The factors combined to effectively disable this waste elimination technique.

7 Improvement of product quality at source offered the ability to reduce the queues of material waiting for concession approval, and increase productivity through reduced levels of rework and scrap. All three cases identified levels of opportunity for improvement that made this an attractive course of action. Support in local and supply chain areas were high. At first asking the support

for the goal of improved product quality was strong in factory service areas. However, the enthusiasm to participate in the activities required in order to improve product quality was lower. This lower level of support prevented some process changes to improve product quality in the case of the titanium undercarriage assemblies. However, process improvements in the cases of the rib assemblies and the buttstraps attracted a sufficiently strong measure of support for developments to be made.

8 Mixed production offered the highest opportunity in the case of the titanium undercarriage assemblies due to the different production rates of its products (6 to 45 per year). The result of not closely coupling supply with demand would be excess inventory or inability to deliver when required. Strong local operator/manager support was present in all areas. These factors led to mixed production being pursued in the case of the titanium undercarriage assemblies.

9 The opportunity for improvement offered by layout improvement was high for all three cases. Due to the layout at the start of the KPS implementation the highest opportunity was for ribs, then buttstraps, and then TUAs. Despite enthusiasm from local operators/managers, the factory support managers withheld support for layout improvement for the buttstrap facility at the time as there was an unacceptably high risk that customer deliveries would be disturbed. These factors resulted in the manufacturing facilities for the ribs and titanium undercarriage assemblies being reorganised according to the material flow in the process. The buttstrap local management sought to foster support for layout improvement by removing the cause of the support being withheld. It was anticipated that layout improvement would command stronger support once the barriers were removed, and this would enable buttstrap layout improvement.

10 As a method to reduce the level of work in progress, visual and pull control techniques provided a high opportunity for improvement in all three cases. These techniques offered highest opportunity for buttstraps and titanium undercarriage assemblies. Strong local operator/manager support allowed its application in the case of the buttstraps and titanium undercarriage assemblies. However, local operator/manager support was lower than that offered to the activities of layout improvement and setup reduction. This effectively disabled visual and pull control techniques for rib assemblies as

insufficient managerial capacity was available to modify the manufacturing system. The outcome of these factors was the pursuit of visual and pull control waste elimination techniques by the buttstraps and titanium undercarriage assemblies whilst the techniques of layout improvement and setup reduction were pursued by the rib assemblies.

11 A substantial improvement in the organisation of the workplace through housekeeping/4S/5S/6S/workplace organisation activities was pursued in the TUAs, and this was coupled with a window of opportunity presented by the large scale improvement in layout. The local managers and operators of the other cases did not consider the opportunity for improvement presented by workplace organisation to be significant.

12 Pull control systems were discussed together with visual control systems, above. In addition to this, production to an internal schedule which incorporated a safety time buffer was demanded by the customer due to historical inability to deliver on time. This resulted in overproduction as products were manufactured in advance of their actual requirement. Hence, there was an opportunity to reduce inventory in the manufacturing systems by coupling production with demand from the customers using a pull system. The supply chain (customer) managers were not willing to support changes to the schedule mechanism. Consequently, the internal schedule for production was retained. This was identified as an area to develop support to allow future improvement of the manufacturing systems.

13 The local managers and engineers exercised a deliberate policy of delaying autonomation activities as they universally concluded that there was a considerable quantity of waste in the manufacturing systems that would need to be removed prior to incurring the expense involved in this technique. Coupled with this was the knowledge that the introduction of autonomation can be easier and cheaper once the manufacturing process has been simplified or streamlined in advance through the elimination of waste. Without local support, autonomation was not pursued in any of the three cases. However, local managers were aware of the future possibilities that autonomation allowed.

An initial determinant of local operator/manager support was exposure to background education and detailed training regarding KPS, and participation in the development of improvement ideas. This support benefitted from continuous reinforcement by making modifications to the manufacturing system according to the improvement ideas produced locally as soon after their development as possible, and publicising the improvements in performance measures. Maintaining production created difficulties in releasing people for education and training purposes, and in making modifications to the manufacturing system. This increased the problem of how to implement improvement ideas quickly, as they could be developed more rapidly than introduced. It meant developing a subsystem in the manufacturing system whose role was to rapidly process large numbers of improvement ideas, and change the manufacturing system itself. This was assisted by targeting development of simple improvement ideas and local budget holding for very small scale expenditure.

The application of a prescriptive approach to JIT implementation would not have considered the local variations between the three cases identified above. This is reinforced by observations made of other multiple case studies, presented in literature, where different cases have been shown to pursue alternative approaches to JIT implementation. A tailored approach to implementation was taken in all three cases. The solution to the JIT implementation dilemma in each instance has been shown to be modelled by the combination of the two variables. These were the level of perceived opportunity for improvement offered by each waste elimination technique, and the measure of distributed support for each waste elimination technique.

4.7 Conclusions

The benefits, financial and non-financial, resulting from the implementation of JIT manufacturing in the three cases at BAe Chadderton have been demonstrated as large. These include inventory reductions of 46%, leadtime reductions of 51%, and productivity improvements of 23%. These translate to a significant one-off inward cash flow and subsequent annual savings for the commercial aircraft operations of British Aerospace. The implementation of JIT manufacturing offers benefits to the commercial aircraft manufacturing industry.

The three cases demonstrated significant differences in the waste elimination techniques used. This was despite all three cases being in highly similar environments and having near identical macro environmental factors. All were in the same industry, the same company, the same factory, covered similar manufacturing processes, were of similar size, and produced in similar volumes and varieties. The wide variation in the implementation of JIT, and specifically the use of waste elimination techniques, was the result of implementation issues which were determined locally on a case by case basis.

Two variables were identified as important in the approach taken during the implementation of JIT manufacturing. These modelled the development of the solution to the JIT implementation dilemma in each case. They were:

- the level of opportunity offered by each waste elimination technique for improvement of manufacturing system performance that was perceived by local managers, engineers, and operators, factory service managers, and supply chain managers; and
- the measure of support from local operators/managers, factory service operators/managers, and supply chain (supplier and customer) managers for the application of each waste elimination technique.

For each case, any waste elimination technique that enjoyed a high perceived level of opportunity for improvement and which attracted strong support from local, factory service, and supply chain areas was shown to have played an important role in the improvement of the manufacturing system. Those which did not enjoy a high level of opportunity or failed to attract strong support were not important in improving the manufacturing system. The variables of opportunity and support allowed waste elimination techniques to be prioritised to present practical guidance on how JIT manufacturing should be implemented on a case by case basis. Further details of the three cases and the research method are presented in Appendix D.

Chapter Five

Role Of Opportunity And Support

5.0 Introduction

This chapter defines and explores two concepts identified in chapter four: the "level of perceived opportunity for improvement" and the "measure of distributed support". Their relationship with the Chadderton Industrial Cases and literature is discussed. Finally, they are combined with the pyramidal model of JIT manufacturing, developed in chapter two. This illustrates the role of the concepts in the process of JIT implementation. They provide a principle for JIT implementation which is applied in the practical tailored framework, developed in chapter six.

5.1 Concept Of The Level Of Perceived Opportunity For Improvement

The level of perceived opportunity for improvement is defined by the author as:

> "the benefit, weighed against costs, anticipated as a result of the application of the specific waste elimination technique to the particular manufacturing system in its present state, assuming that the application of the technique would be successful".

Benefit is the magnitude of the contribution towards a defined set of objectives. The perceived opportunity would be estimated for each waste elimination technique considered for the manufacturing system under development. The level of opportunity from low (0) through to high (9) would be assigned for each waste elimination technique relative to all other techniques considered. A practical method to evaluate the perceived opportunity for improvement for a range of waste elimination techniques is presented in chapter six, "Practical Tailored Framework For JIT Implementation".

For a given manufacturing system in a given state, a number of waste elimination techniques would present different levels of opportunity for improvement relative to each other. Also, for a given waste elimination technique, different manufacturing systems would generate contrasting levels of opportunity for improvement. The purpose of evaluating the perceived opportunity for improvement for each waste elimination technique is to identify those techniques which present the greatest probability of return on the process of JIT implementation. This ensures that waste elimination techniques with a low perceived opportunity for improvement do not consume limited resources for little return, which risks failure of the JIT implementation as early and continued successes are not realised. The value of this task is highlighted by Lockamy and Cox (1991) who observed that due to the variety of techniques comprising JIT, it is crucial that an organisation places an initial emphasis on defining those techniques which will enhance its competitive position, as opposed to selecting techniques that are "easy to do", and locations that are "easy to implement". Youngkin (1984) also identified the need to identify areas of opportunity prior to implementation of changes to the manufacturing system.

Cases of the evaluation of perceived opportunity for improvement are presented in literature, with demonstrations of how the process of JIT implementation was affected. At several stages throughout a narrative of JIT implementation in the case of a machinery manufacturer, Cheng and Musaphir (1993) identified which specific waste elimination techniques were pursued according to the level of opportunity for the elimination of waste. Others were not pursued or put on hold as they did not offer significant improvement. Also, the opportunity for improvement offered by eight waste elimination techniques for a bottling operation were evaluated by Finch and Cox (1986). This clearly identified high perceived opportunity for improvement to be gained from some of the waste elimination techniques considered, and less benefit offered by other techniques. Spurgeon (1984) presented two cases of JIT implementation within GE. One case was high volume housewares and the other was low volume switchgear. Each case was different in terms of the combinations of waste elimination techniques used, and their sequence of use. An instance of JIT manufacturing in the commercial aircraft manufacturing industry was presented by

Schonberger (1984). This identified opportunities for improvement for particular waste elimination techniques such as levelled production and pull control. Schonberger also highlighted opportunities regarding specific waste elimination techniques in cases of shipbuilding. Hay (1988: 3-5) presented cases from Hutchinson Technology Inc. who started the process of JIT implementation with an emphasis on improvement of product quality due to the significant opportunity for improvement that this was perceived to offer. Following this, six pilot areas at the same manufacturing site then pursued different waste elimination techniques.

Further demonstrations can be drawn from the Chadderton Industrial Cases. For example, in the buttstrap case JIT purchasing and preventive maintenance were perceived to offer a lower level of opportunity than setup reduction, layout improvement, and visual and pull control techniques. Also, JIT purchasing and mixed production were perceived to offer a notably higher level of opportunity in the case of titanium undercarriage assemblies than the other cases of rib assemblies and buttstraps.

Hence, all waste elimination techniques do not present equal opportunity for improvement. It is important to accept the role of opportunity in the process of JIT implementation and be able to identify the level of opportunities for improvement presented by waste elimination techniques.

5.2 Concept Of The Measure Of Distributed Support

The wide reaching nature of the changes made to a manufacturing system during the process of JIT implementation will at various stages require support distributed in local production areas, factory service functions, and the supply chain. For the purposes of this thesis the measure of distributed support at a point in time is:

> "the ability and willingness to perform the activities required for, and to accept the anticipated consequences arising from, the application of the specific waste elimination technique in the manufacturing system according to: the local production area; the factory service functions; and the supply chain".

The measure of distributed support would be evaluated for each waste elimination technique considered for the manufacturing system under development, and for each of the local production area, the factory service functions, and the supply chain. The measure of support from weak (0) through to strong (9) would be assigned for each waste elimination technique for each of the local production area, the factory service functions, and the supply chain, relative to all other techniques considered. This provides three independent axes of the measure of support, Figure 5.1, and this can be presented in a radar diagram. The three axes can be subdivided if very different levels of support exist within one area. This is also shown in Figure 5.1. A practical method to evaluate the measure of distributed support in each of the local production, factory service, and supply chain areas for a range of waste elimination techniques is presented in the next chapter.

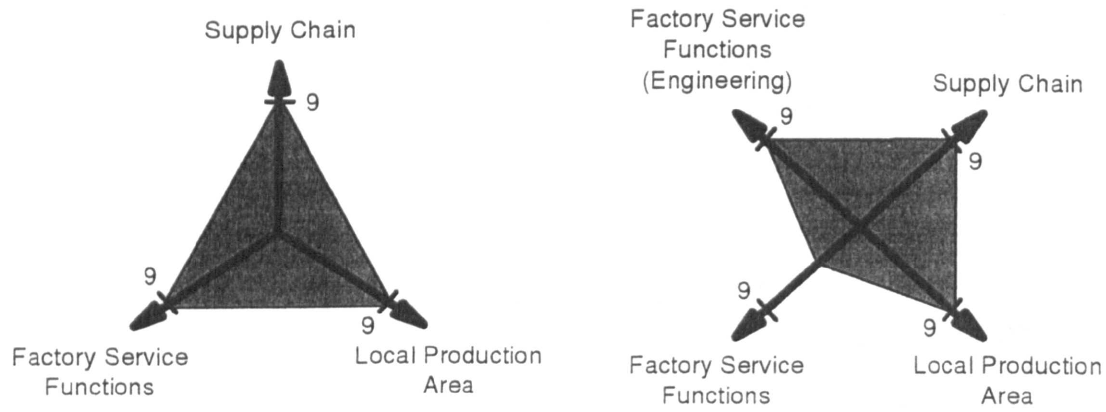

Figure 5.1: Distributed support radar diagram.

For a given manufacturing system at a point in time, a number of waste elimination techniques would each attract different measures of distributed support relative to each other. Also, for a given waste elimination technique, different manufacturing systems would result in contrasting measures of support. The purpose of evaluating the measure of support is to avoid attempting the implementation of waste elimination techniques that are inadequately backed across the local production area, the factory service functions, and the supply chain. This reduces the risk of implementation failure. It will also have the effect of increasing the benefits achieved through the process of JIT implementation by pursuing those waste elimination techniques that are most suited to the specific manufacturing context.

The level of support distributed through the three areas required to ensure successful implementation of a waste elimination technique can be different from one technique to another. This can be demonstrated by consideration of the waste elimination techniques of setup reduction and JIT purchasing. Setup reduction may succeed with strong local production area support, partial factory services support, and weak supply chain support. However, JIT purchasing may require strong local production area support, partial or strong factory service function support, and strong supply chain support. This again can be corroborated by analysis of the Chadderton Industrial Cases.

The measure of distributed support that is required for successful use of a given waste elimination technique can also be shown to depend upon the approach taken to its application. Hence, the measure of distributed support that is required may vary from one case to another. This is demonstrated by practical examples identified during this research.

Example 1. Setup reduction may require strong local production area support and neutral factory service function support and supply chain support if the means to shorter setups is restricted to the layout of ancillary equipment (eg. racking) in the local production area.

Example 2. Setup reduction may require strong local production area support and factory service function support and neutral supply chain support if the jig and tool designs are affected by the proposed shorter setups.

Example 3. Setup reduction may require strong support throughout if material supply conditions are affected by the proposed shorter setups.

Example 4. Setup reduction may require strong support throughout if product design is affected by the proposed shorter setups.

Measures of distributed support that are required for successful implementation of waste elimination techniques are proposed for a general case in Table 5.1.

Cases of the measure of distributed support are presented in literature, with demonstrations of how the process of JIT implementation was affected. Arogyaswamy and Simmons (1991) identified that different measures of support from operators in the local production area would change the sequence of the activities involved in the process of JIT implementation. In order to determine which element of JIT should be pursued first, Bicheno (1991: 9) suggested that whichever attracted strongest support should lead. Finch (1986) showed that firms would need to gain support from suppliers in order to achieve elements of JIT purchasing, such as modifying delivery schedules, and that small firms may experience difficulty with this.

The Thirteen Core Waste Elimination Techniques	Distributed Support Required		
	Local Production Area	Factory Service Functions	Supply Chain
Flexible/cross trained workforce and job enlargement/enrichment	strong	strong	weak
WIP reduction and small lot sizing	strong	partial	partial
JIT purchasing	strong	partial/ strong	strong
Total productive maintenance/preventive maintenance	strong	strong	weak
Setup reduction	strong	partial	weak
Product simplification, component standardisation, and product modularisation	partial/ strong	strong	strong
Quality at source and operator centred quality control	strong	strong	partial
Levelled and mixed production	strong	weak	strong
Layout improvement: cellular manufacturing/group technology/dedicated lines/"U" shaped lines	strong	strong	weak
Visual control including standard operations and andon systems	strong	weak	weak
Housekeeping/4S/5S/6S/workplace organisation	strong	strong	weak
Pull control/kanban	strong	partial	strong
Autonomation/autonomous defect control	strong	strong	weak

Table 5.1: Proposed distributed support for waste elimination technique implementation

Further instances can be identified from the Chadderton Industrial Cases. For example, in the case of the buttstraps, layout improvement and product simplification enjoyed strong support in the local production area, and weak support in the factory service functions and the supply chain. However, setup reduction enjoyed strong support in the local production area and factory service functions, with weak or partial support in the supply chain. Further to this, preventive maintenance attracted weak support in the local production area, strong support in factory service areas, and neutral support in the supply chain. Also, layout improvement enjoyed strong support from the factory service functions for rib assemblies and titanium undercarriage assemblies, but attracted only weak support from the factory support service functions for the buttstraps.

It is unlikely in an organisation at the start of the process of JIT implementation that everyone in the company and supply chain will support all waste elimination techniques considered. It is also unlikely that everyone will resist every waste elimination technique. The importance of the distributed measure of support is to clearly identify which waste elimination techniques are enabled and ready for implementation, and those that are disabled in terms of implementation in the manufacturing system.

5.3 Opportunity And Support Within The Pyramidal Model Of JIT Manufacturing

The concepts of the level of perceived opportunity for improvement and the measure of distributed support can be combined with the pyramidal model of JIT manufacturing to demonstrate the basis of an approach to the process of JIT implementation, Figure 5.2. The first diagram shows the starting point with a pyramid of building blocks whose height symbolise the performance of the manufacturing system. The base of the pyramid is constructed of blocks which symbolise support levers. Above these are placed other blocks which represent waste elimination techniques. On these are placed yet more blocks that represent performance measures in which improvements are made. Hence, as more blocks representing performance measures are added, the range and reach of business performance improves. The pyramid is constructed by adding blocks in a ordered manner.

Attempted implementation of a waste elimination technique which does not have sufficient distributed support may fail. This is shown in the second diagram. This depicts the role of the measure of distributed support in the process of JIT implementation. That is, the measure of distributed support must be sufficiently strong to qualify a waste elimination technique for implementation. It is important to identify when a waste elimination technique has insufficient support in order to prevent its implementation. Otherwise, finite resources for JIT implementation will be misdirected towards the pursuit of a waste elimination technique which presents unacceptably high risks of failure. Benefits arising from JIT implementation will be unnecessarily reduced and delayed. This may lead the company to incorrectly conclude that the waste elimination technique in question, or even JIT manufacturing itself, is unsuitable in their specific manufacturing context.

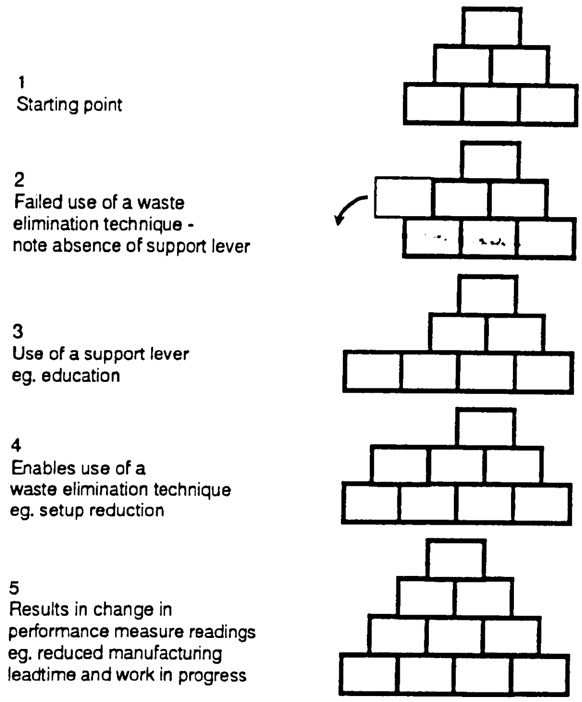

Figure 5.2: The process of JIT implementation using the pyramidal model

Support levers may be employed to increase the measure of distributed support that waste elimination techniques attract. Increased measures of support improve the likelihood of a waste elimination technique being successfully employed. Successful application of a waste elimination technique with a high level of perceived opportunity for improvement will generate improved performance measure results. These steps are shown in the third, fourth, and fifth diagrams. The dimensions of the pyramid in the fifth diagram are larger than the first diagram, and this symbolises the improved performance of the manufacturing system.

This also depicts the role of the perceived opportunity for improvement in the process of JIT implementation. That is, the perceived opportunity for improvement should be sufficiently high to justify the implementation of a waste elimination technique. It is then important to identify when a waste elimination technique has insufficient opportunity in order to prevent its implementation. Otherwise, finite resources for JIT implementation will be misdirected towards the pursuit of a waste elimination technique which presents unacceptably low returns. This may also lead the company to incorrectly conclude that the waste elimination technique in question, or even JIT manufacturing itself, is unsuitable in their specific manufacturing context.

In each of the Chadderton Industrial Cases, the waste elimination techniques implemented were those which attracted the strongest measure of distributed support and also the highest level of perceived opportunity for improvement.

Keller and Kazazi (1993) stated that support from all areas and all levels within a company is required for full implementation of JIT manufacturing. This is consistent with the wide reaching effects of JIT implementation that were presented in chapter four. However, the process of JIT implementation can be started or progressed further provided that one or more waste elimination techniques enjoys sufficient distributed support and that opportunity for improvement is present. Whilst support from all areas and all levels within a company may be required in a highly mature JIT implementation, it is not a requirement to begin the process of JIT implementation.

5.4 Conclusions

The concepts of the perceived opportunity for improvement and the measure of distributed support have been defined and illustrated using excerpts from the analysis of the Chadderton Industrial Cases and previous research in literature. Individual waste elimination techniques have been shown to attract different measures of distributed support and levels of opportunity for improvement.

The process of JIT implementation was demonstrated to be influenced by the two concepts using the pyramidal model of JIT manufacturing. This identified that the process of JIT implementation would benefit from pursuing the application of waste elimination techniques that attracted a strong measure of distributed support and provided a high level of perceived opportunity for improvement.

There is a requirement for practical mechanisms to evaluate the measure of distributed support and the level of perceived opportunity. These are presented in the following chapter within the practical tailored framework for JIT implementation.

The process of building support to apply waste elimination techniques to generate improved performance measure results is also incorporated into the framework developed in the next chapter.

Chapter Six

Practical Tailored Framework For JIT Implementation

6.0 Introduction

This chapter presents the practical tailored framework for the implementation of JIT manufacturing. This is based on the findings of the case studies and integrated with research from other subject areas and the pyramidal model of JIT manufacturing.

6.1 Framework Overview

Elements of the framework draw upon work of other researchers in some areas, particularly strategy formulation, performance measurement selection, and detailed application guidance for waste elimination techniques. However, the main novel feature of the framework is the integration of several practical methods into a process to support the formulation of tailored action plans for the process of JIT implementation that combine the concepts of the level of perceived opportunity and the measure of distributed support. These action plans provide a tailored solution to the JIT implementation dilemma.

The structure of the framework is summarised in Figure 6.1, showing the main phases, the stages within them. The relationships between the main phases and stages are shown as arrows. The phases, stages, and relationships between these are explained in detail in this chapter. Five phases are shown, with the start up phase leading into a cyclical or feedback system. This cyclical system is composed of the four remaining phases of: strategy and objectives; analysis and plan; action; and evaluation, feedback and learning. During the process of JIT implementation, the four cyclical phases are repeated, giving multiple iterations of the framework. The elapsed time for one iteration of the framework is the framework period. This can be adjusted to suit the specific manufacturing context, and is anticipated to be no longer than ten to twelve weeks in duration. This relatively short period is to: focus attention on specific activities throughout the framework period; allow frequent reevaluation of the progress and process of JIT implementation; reduce the complexity of the planning required for JIT implementation; and reduce the time over which it is necessary to forecast the activities required for JIT implementation.

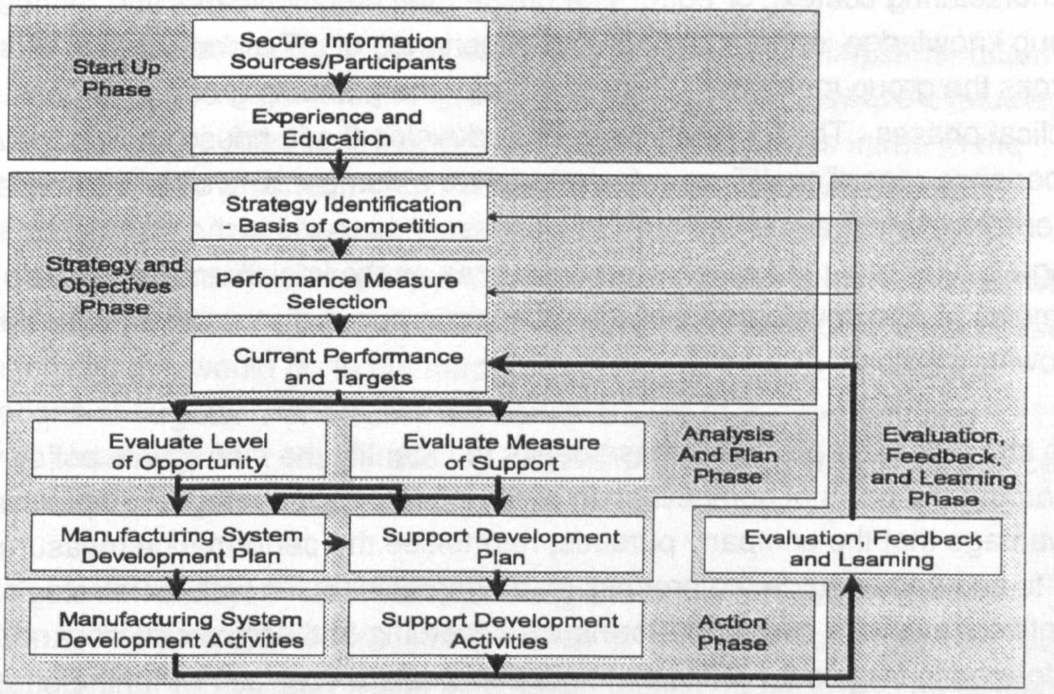

Figure 6.1: Overview of practical framework for JIT implementation - summary

The framework pursues the elimination of waste in the manufacturing system, and assumes that this is consistent with and can contribute towards the strategic objectives of the company.

The supporting organisation for the framework is based around a planning group, which should be led by the person responsible for the operation of the area of the manufacturing system in which the process of JIT implementation is being pursued.

The start up phase establishes the planning group, which performs the main tasks of the framework. This group should be cross-functional. This is necessary to reflect the nature of the changes to the manufacturing system that can occur during the process of JIT implementation. As the degree of cross-functional participation in the planning group is increased, the guidance developed for JIT implementation from the framework will become more suited to the manufacturing system, and those affected by it. The planning group provides the understanding of JIT manufacturing and detailed knowledge of the specific manufacturing context. Establishing the planning group involves securing the participation of a group of people with the combined knowledge required to start the process of JIT implementation. These may be internal and external to the company. Individual members may have detailed understanding of JIT manufacturing, or knowledge of the specific manufacturing context, or both. The phase then communicates and refines the group knowledge, understanding, and experience of JIT manufacturing more widely across the group members. Once prepared, the planning group then goes on to the cyclical phases. The framework seeks to develop the in-house knowledge and experience regarding JIT manufacturing over a number of cycles. Hence, although external knowledge sources may be necessary or useful in the first cycles, they are progressively replaced with in-house sources as the implementation develops. The formulation and development of the planning group is discussed in more detail in the following section.

The strategy and objectives phase seeks to: identify the managerial policy regarding the basis of competition in order to clarify the strategic competitive advantage that the company pursues; harmonise the performance measures that are to be used to guide the process of JIT implementation with the strategy identified; evaluate current performance according to these measures; and, identify performance targets for JIT implementation that are consistent with the strategy identified. Its purpose is to ensure that the JIT implementation process supports the strategic business requirements of the company, and its customers and suppliers.

The analysis and plan phase considers the concepts of the level of perceived opportunity for improvement and the measure of distributed support, with the waste elimination techniques and support levers of the pyramidal model to create two time phased action plans. The first of these is the manufacturing system development plan. This identifies the waste elimination techniques to be applied during the current framework cycle to the manufacturing system. It provides a tailored solution to the JIT implementation dilemma in a manner that seeks to meet the objectives identified in the strategy and objectives phase. The second is the support development plan. This identifies particular support levers that are to be pursued in specific parts of the manufacturing system to cultivate future support for particular waste elimination techniques to be applied in later framework cycles. The two plans provide instructions for the process of JIT implementation to the next phase.

The action phase concurrently executes the manufacturing system development plan and support development plan. This actively modifies the manufacturing system using the waste elimination techniques identified in the manufacturing system development plan, and applies support levers to increase the measure of distributed support for the use of additional waste elimination techniques in future manufacturing system development plans during subsequent framework cycles.

The final phase of each cycle of the practical framework for JIT implementation is the evaluation, feedback, and learning phase. The earlier phases are evaluated. Feedback may be provided to the pyramidal model and changes made to the support levers, waste elimination techniques, and performance measures considered within it. Also, the mechanisms used to collect information in the framework may be modified as people in the company become more familiar with JIT manufacturing. The framework restarts in the strategy and objectives phase. Conventionally, this would go to the reappraisal of current performance and modifications of targets. Periodically the earlier stages of the strategy and objectives phase require consideration to ensure that strategy and performance measures remain suited to business priorities.

With each framework cycle: the manufacturing system is developed as waste elimination techniques are applied; performance of the system changes; the level of perceived opportunity for each waste elimination technique fluctuates as openings are exploited and further possibilities emerge; the measure of distributed support varies as support levers are employed; further support levers, waste elimination techniques, and performance measures are added to the pyramidal model of JIT manufacturing; and the knowledge and experience of JIT manufacturing retained within the company increases in detail and becomes more widespread.

The framework is intended to be robust in terms of the level of cross-functional participation. Low levels of cross-functional participation obstruct the cross-functional changes that are required for a mature implementation of JIT manufacturing, and stunt the growth of the benefits from employing the framework

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Support Evaluation Interview Form

Local/Factory Service/Supply Chain Area:
Maintenance Department (Factory Service Area)

Manufacturing System Area:
Buttstrap Cell

	Waste Elimination Technique	Support (0-9)	Reasons For Support Being Offered / Withheld
1:	*Multiskilling*	7	*Particularly basic maintenance*
2:	*WIP reduct'n/small batch*	6	
3:	*JIT purchasing*	4	*No strong opinions - neutral*
4:	*TPM*	9	*For bottleneck machines to begin with*
5:	*Setup reduction*	8	*Prepared to assist where required*
6:	*Product simplification*	2	*Cannot see this being supported elsewhere*
7:	*Quality at source*	6	
8:	*Levelled/mixed production*	4	*No strong opinions - neutral*
9:	*Layout improvement*	3	*Unlikely to fit budget - some machines are expensive*
10:	*Visual control methods*	6	*Will provide noticeboards if required*
11:	*Workplace organisation*	3	*Would couple this with future layout improvement*
12:	*Pull control*	4	*No strong opinion - neutral*
13:	*Autonomation*	7	*Particularly regarding conventional machining*

Table 6.4: Support Evaluation Interview Form example layout

6.4.3 Manufacturing System Development Plan

The objective of this analysis is to generate a solution to the JIT implementation dilemma in a manner that is tailored to the specific manufacturing context. The task is to process the information regarding the perceived opportunity for improvement and the measure of distributed support to generate a realistic time phased plan that identifies which waste elimination techniques are to be applied, where in the manufacturing system, and when. This stage requires the widest cross-functional participation of any because this determines how the manufacturing system itself will be changed during the remainder of the present framework cycle. A process is shown in Figure 6.7.

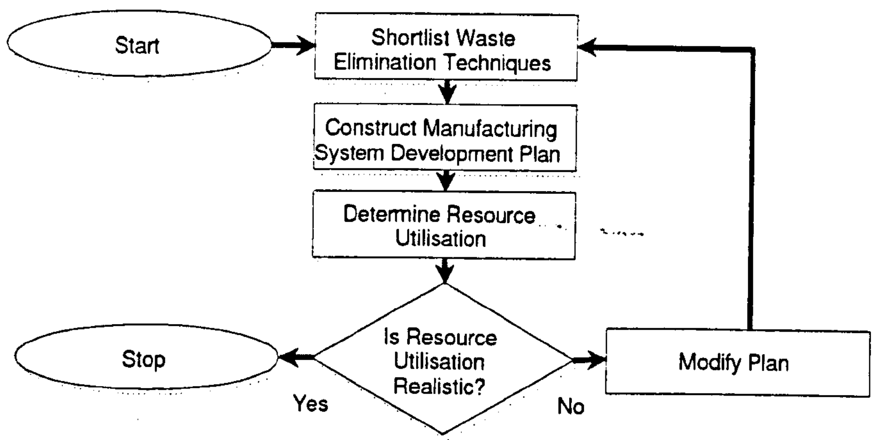

Figure 6.7: Manufacturing system development plan stage

The first step for the planning group is to identify a shortlist of waste elimination techniques to be included in the manufacturing system development plan from those considered throughout the framework. The waste elimination techniques with the strongest combination of distributed support and opportunity for improvement are included. Some waste elimination techniques may offer high opportunity for improvement but attract only weak measures of distributed support, despite the rewards of implementation on offer. Application in these conditions should be postponed as they present a high risk of failure. Any failed application will seriously reduce the prospects of the particular waste elimination technique attracting strong distributed support in the future that could then lead to successful use. Hence, the shortlist consists of waste elimination techniques with strong distributed support, and within this subgroup, only those with the most significant opportunity for improvement.

The manufacturing system development plan is constructed in the second step, from the shortlist. The duration of the plan is for one framework cycle only. The short length of the framework period, usually ten to twelve weeks, eliminates the need for sophisticated planning or forecasting of activities, which carries risks even when performed by those with experience in JIT manufacturing. The short planning window may result in some waste elimination techniques being included in a sequential series of manufacturing system development plans. The plan details the activities involved in the application of the shortlisted waste elimination techniques and assigns resources to these. The short duration of the manufacturing system development plan also allows the process of JIT implementation to be frequently adjusted to take advantage of opportunities as they are identified, whilst a plan of action developed through cross-functional participation provides clear direction for activities at any point in time.

The manufacturing system development plan is evaluated to ensure that reasonable demands are placed on: the manufacturing system which may be required to maintain deliveries to customers throughout the duration of the plan; and the people in local, factory service, and supply chain areas whose attention is required to develop the manufacturing system itself. If the plan is determined to be unrealistic in any conditions, the above process is modified accordingly. When the plan to develop the manufacturing system is considered by the planning group to be realistic in the use of waste elimination techniques, and the availability of resources, then the agreed plan is taken forward to the action phase.

6.4.4 Support Development Plan

The objective of this stage is to identify which support levers should be employed, where in the manufacturing system, and when, in order to increase the measure of distributed support over the course of the current framework cycle and into the next. The purpose of this is to allow the application of further waste elimination techniques in future manufacturing system development plans. The steps in this stage are shown in Figure 6.8.

The first step is to identify a shortlist of waste elimination techniques that offer a high level of opportunity for improvement, but whose inclusion in the manufacturing system development plan is restricted or postponed due to its weak measure of distributed support. The second step is to locate for each of the shortlisted waste elimination techniques which of the local, factory service, or supply chain areas of the manufacturing system have withheld support. These are identified from the Support Evaluation Interview Form survey information collected during the evaluation of the measure of support. The third step requires the cause for support being withheld to be identified, again from the survey information. Ishikawa diagrams (Newman 1995) can be used to assist the identification of the root cause of the lack of support. The root cause may not always be clear, and there are no fixed or deterministic relationships between the area withholding support and the root cause. This can be demonstrated by practical industrial examples identified during this research:

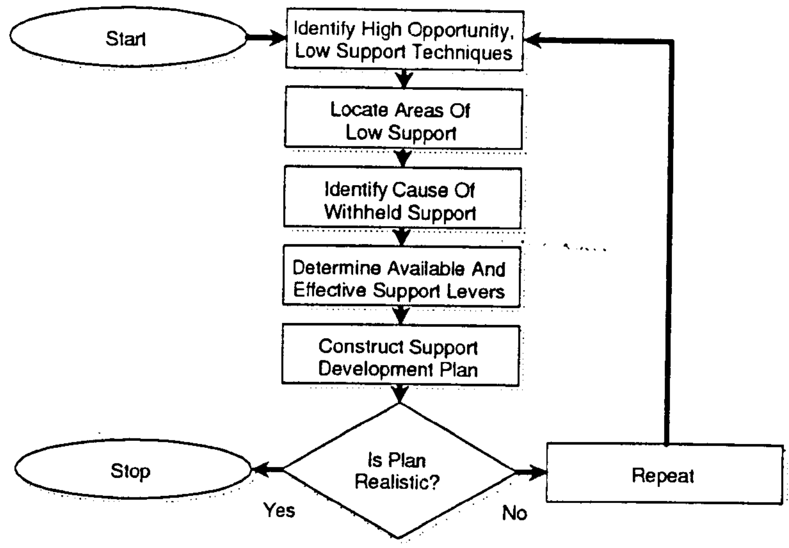

Figure 6.8: Support development plan stage

Example 1. A supplier may withhold support for JIT purchasing of raw materials because the manufacturer is responsible for only 0.1% of the supplier's sales. In this instance, the wrong supplier may be being used, or the correct supplier may be being used in the wrong way.

Example 2. A supplier may withhold support for JIT purchasing of raw materials because the supplier is located 5,000 miles from the manufacturer. In this instance, the wrong supplier may be being used and a local alternative should be developed, or the manufacturer or supplier may be in the wrong location.

Example 3. A supplier may withhold support for JIT purchasing of raw materials as the purchasing department of the manufacturer pursue practices that are contrary to JIT manufacturing, such as awarding very short term contracts between multiple suppliers, or buying in large quantities to secure volume discounts. In this instance, the purchasing department of the manufacturer should be approached and made aware of the requirements of JIT manufacturing. Those monitoring the purchasing department may also be required to adjust the performance measures used to evaluate the purchasing function.

Hence, the relationship between the area withholding support and the root cause is dependent upon the specific manufacturing context. For each shortlisted waste elimination technique, the fourth step requires support levers, such as those of Table 2.5, to be evaluated to determine whether they are: available for use in the specific manufacturing context; and potentially effective in eliminating the root cause of support being withheld. The proposed support development plan is then constructed in the fifth step from the support levers deemed to be available and effective. As with the manufacturing system development plan, the duration of the plan is for one framework cycle only. The plan identifies the support levers that are to be employed, where in the local, factory service, or supply chain areas of the manufacturing system, and when.

The role of the support development plan was supported by Ansari and Modarress (1986). They investigated seven implementation issues, which were mainly lack of support from different areas of a manufacturing system, and sought to identify how support could be developed. They identified issues that could block support from the different areas of the manufacturing system, and suggested the use of particular support levers to develop support where levels were insufficient.

6.4.5 Analysis And Plan Phase Summary

The planning group process the strategy and the long and short term objectives identified earlier to emerge from the analysis and plan phase with:

- an evaluation of the perceived level of opportunity for improvement offered by each of the waste elimination techniques considered;
- an evaluation of the measure of distributed support for each of the waste elimination techniques considered;
- a manufacturing system development plan which provides a tailored solution to the JIT implementation dilemma. This details which waste elimination techniques will be applied, where in the manufacturing system, and when; and
- a support development plan that actively seeks to strengthen the measure of distributed support so that additional waste elimination techniques can be applied in future manufacturing system development plans.

These are carried forward into the action and the evaluation, feedback, and learning phases.

6.5 Action Phase

This phase occupies the majority of the framework cycle period. The objectives of this phase are: to modify the manufacturing system such that performance is improved to achieve the short term objectives of the framework cycle; and, to strengthen the measure of distributed support for waste elimination techniques. The action phase, Figure 6.9, involves the application of the waste elimination techniques identified in the manufacturing system development plan, and the pursuit of the support levers highlighted in the support development plan.

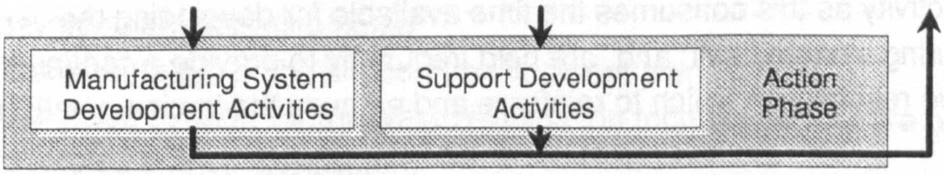

Figure 6.9: Action phase

6.5.1 Manufacturing System Development Activities

The task of this stage is to apply the waste elimination techniques identified in the manufacturing system development plan in order to modify the manufacturing system itself, and hence achieve the short term objectives of the framework cycle and contribute towards the longer term objectives. Current literature contains extensive volumes on detailed guidance for the application of each of a wide range of waste elimination techniques. A selection of important references to these publications are presented for each waste elimination technique of the pyramidal model of JIT manufacturing in Appendix C.

The planning group members are assigned to the various activities identified in the manufacturing system development plan. Responsibility for particular activities may be distributed to working sub-groups within the planning group itself. It is likely that non-planning group members will become involved with the process of JIT implementation at this stage. This is desirable in order to raise the overall level of education and experience regarding the principles and practices of JIT manufacturing in the people within the manufacturing system as a whole.

The activities of the manufacturing system development plan should be periodically reviewed by the planning group throughout the action phase. Although the format for this review can be tailored to suit the preferences and requirements of the planning group, it is important that the reviews: are not held in a meeting room if most of the manufacturing system development activities are pursued in a shopfloor, design, support service environment, or a supplier's plant; are attended by as many of the planning group members as possible as the reviews provide an excellent opportunity for further developing the experience of JIT manufacturing held by the planning group; can be attended on an observer basis by non-planning group members as the reviews also provide an excellent opportunity to disseminate understanding of JIT manufacturing throughout the manufacturing system; require a minimal amount of preparation by each of the planning group members responsible for each activity as this consumes the time available for developing the manufacturing system itself; and, are held frequently to provide a continual supply of progressive results with which to reinforce and enthuse the implementation process.

6.5.2 Support Development Activities

The objectives of the support development activities are to: increase support within particular areas of the manufacturing system for the future use of particular waste elimination techniques that are perceived to offer a high opportunity for improvement and are currently prohibited or restricted in their application; generally increase the level of education and experience regarding JIT manufacturing in all areas of the manufacturing system; and, increase the level of cross-functional participation in the planning group if insufficient during the current framework cycle. The activities follow the support development plan, constructed in the analysis and plan phase. The planning group leader and members are assigned to particular activities.

Efforts are targeted towards those areas of the manufacturing system who are withholding support for waste elimination techniques that are perceived to offer a high opportunity for improvement. Such waste elimination techniques are expected to be included in a subsequent manufacturing system development plan, for application in the manufacturing system. As far as possible, the temptation to provide training at the expense of all else must be resisted. It can be beneficial to acknowledge that training has a shelf life during which it must be seen to be applied to the manufacturing system, otherwise the viewpoints that "it has not worked", or that the company "have tried that" may prevail. Hence, the provision of training should not be deployed too far in advance of the expected application of the various waste elimination techniques.

6.5.3 Action Phase Summary

Throughout the action phase, the main deliverables are:

- development of the manufacturing system using the activities identified in the manufacturing system development plan;
- regular monitoring sessions to demonstrate how JIT manufacturing can be applied in the context of the specific manufacturing system;
- performance measures recorded and results of the manufacturing system development activities noted;
- implementation of the support development plan;
- increased support for the waste elimination techniques that are postponed or restricted in their application;

6.6 Evaluation, Feedback and Learning Phase

This phase reviews the earlier phases of the framework cycle to provide the benefits of the experience from the current and any previous framework cycles into future cycles, Figure 6.10. Following this analysis, another cycle of the framework is started.

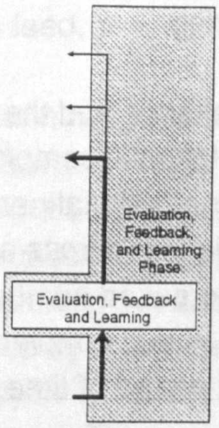

Figure 6.10: Evaluation, feedback, and learning phase

A range of conclusions may be drawn from the review of the earlier phases. For each support lever, waste elimination technique, performance measure, and area of the manufacturing system, the planning group may conclude that:

- target selection was under- or over-optimistic;

- evaluation of the level of perceived opportunity for improvement was under- or over-optimistic;
- evaluation of the measure of distributed support was under- or over-optimistic; and
- the framework period was too short or too long.

Other observations that could be made, and conclusions drawn include:
- the need to increase or reduce the area of the manufacturing system in which the process of JIT implementation is being pursued;
- working examples of how waste elimination techniques can be successfully, and unsuccessfully pursued;
- effective and ineffective formats for meetings and progress reviews;
- effective and ineffective formats for the Opportunity Evaluation Worksheet and the Support Evaluation Interview Form;
- the leadership and membership of the planning group;
- allocation of tasks within the planning group, and working sub-groups;
- additional education and training requirements for the planning group to support further progress in JIT implementation.

These conclusions of the review can be used to modify how the framework is employed prior to the next cycle. Also, as the process of JIT implementation matures in the company, additional support levers, waste elimination techniques, and performance measures may be of potential benefit. These are added to the Pyramidal Model of JIT manufacturing.

Once the evaluation of the earlier phases and the feeding back of findings into the framework to evolve the approach taken is complete, another cycle of the framework can be initiated. This may consider additional performance measures, support levers and waste elimination techniques, across a wider area of the manufacturing system, and be performed by an increased number of people within the manufacturing system. In this way, the JIT implementation within a company matures from cycle to cycle, over a period of time.

The decision on where to restart the next cycle of the framework can be based on several factors. The participation of new sources of knowledge for the strategy identification stage can justify the redevelopment of the strategy used within the framework. Other factors which may justify this include the introduction of new products by the company, changes in the market (eg. competitor changes, customer changes, and legislative changes), and the attainment of the long term performance targets identified from the earlier strategy. However, if the planning group are satisfied that the performance measures are suited to the objectives of the process of JIT implementation, then the framework may be restarted by a reevaluation of the performance targets.

6.7 Approach to the use of the framework

From surveys of previous cases, JIT implementation is usually started with a pilot project (Sohal, Ramsay and Samson 1993) which was normally a cell or a small unit (Voss and Harrison 1987). According to Bicheno (1991: 97), characteristics of an ideal pilot project include:

- small self-contained area;
- committed supervisors;
- ability to move rapidly with little red tape;
- no other simultaneous projects;
- no bonus scheme barriers;
- reasonably good quality;
- ability to have no works orders;
- good industrial relations climate;
- operator willingness to make changes themselves; and
- the possibility of direct line feed.

For a small company, only one planning group would be required throughout the process of JIT implementation. However, larger companies would consist of manufacturing areas which could not be overseen by one planning group led by one manufacturing manager. In such cases, multiple planning groups would be established. A steering group, composed of each planning group leader, members of senior management, and chaired by a member of senior management, would then meet after each framework cycle to review progress and orchestrate operations between the various planning groups. The process of JIT implementation can be started in one area of a company by one planning group, if necessary with a low degree of cross-functional participation. The process can then be incrementally developed by increasing the degree of cross-functional participation, mainly through the actions of the support development plans, and also by establishing further planning groups for other areas of the manufacturing system. This can create a three level structure for the framework, with one steering committee linked to potentially several planning groups, each of which operates with a small number of working sub-groups.

The structured process formalises JIT implementation within a company by repeating a cycle of:

- identifying performance measures and targets that are consistent with the strategy of the company;
- formulating action plans for developing the manufacturing system and increasing the awareness and support for JIT manufacturing across all areas of the company;
- executing the developed plans, eliminating waste from the manufacturing system and building support and cross-functional participation throughout the company;
- evaluating progress made, and modifying the approach taken throughout each cycle according to the strengths and weaknesses observed.

The specific manufacturing context, performance requirements, perceived opportunity for improvement offered by each waste elimination technique, level of distributed support, and employment of support levers will change over the course of time. This is increased by the knock-on effects of applying waste elimination techniques within the manufacturing system. The cyclical approach of periodically reviewing the manufacturing system allows such changes to be taken into consideration. This is consistent with Fielder, Galletley, and Bicheno's (1993) understanding of the process of JIT implementation which "is an ongoing cyclic process of improvement", where "actions taken in one area will make actions possible in another area".

6.8 Conclusions

This chapter combines:

- the concept of opportunity for improvement;
- the concept of distributed support; and
- the pyramidal model of JIT manufacturing

with processes based on existing research in the areas of:

- strategy formulation;
- performance measurement selection;
- the nominal group technique; and
- waste elimination technique application guidance literature

to create a consistent and practical framework to guide the process of JIT implementation, that can provide tailored solutions to the JIT implementation dilemma. The chapter concentrates on providing pragmatic instructions throughout the steps of collecting and analysing information.

A tailored process of JIT implementation requires knowledge and experience of JIT manufacturing to support decision making throughout. The cyclical approach taken encourages a combination of external knowledge and experience of JIT manufacturing (such as consultants and industry) with internal understanding of the specific manufacturing context. It provides a structured approach to growing in-house knowledge and experience of JIT manufacturing from one cycle to the next, gradually reducing the reliance upon external assistance. The company gains the in-house capabilities required to progress towards a mature implementation of JIT manufacturing.

Two distinct directions of activity are identified. The first is the development of the manufacturing system itself, through the actions specified within the manufacturing system development plan. These are identified by waste elimination techniques with a high level of perceived opportunity for improvement and a strong measure of distributed support. These effectively pursue openings for developing the manufacturing system towards the strategic objectives of the company that are enabled. The second is enhancing support for JIT manufacturing across the various manufacturing areas and all functions of the company, through the actions specified within the support development plan and reviews at regular intervals of the manufacturing system development plan activities. The support development plan is developed from consideration of waste elimination techniques which present a high level of perceived opportunity for improvement, but whose application is hampered by an insufficient measure of distributed support. In effect, this seeks to develop openings for further development of the manufacturing system at a later date.

A supporting organisation is identified for the framework. This is based around a distributed structure of one steering committee overseeing a number of planning groups, each one responsible for a distinct manufacturing area, and each of which supervises a number of working sub-groups in its own area. In order to achieve maturity, the importance of cross-functional participation in JIT implementation is acknowledged. Hence, the second of the two directions of activity is focused upon enhancing support for JIT manufacturing across the company. Despite this, low levels of cross-functional participation do not prohibit the initial steps towards JIT manufacturing to be taken via the first cycles of the framework, provided that they have been carefully selected, based on the analysis of the framework.

Finally, as well as providing tailored solutions to the JIT implementation dilemma, the framework encourages the company to modify the framework itself. This allows the information collection and analysis processes used within the framework to be changed to suit the degree of sophistication within the company regarding JIT manufacturing. Without this, as more and more people within the company acquire ever greater knowledge and experience of JIT manufacturing, the procedures of the framework will become overly-cumbersome. This is a form of waste itself, and it is appropriate that a process to guide continual improvement through the elimination of waste should improve perpetually.

The process of the framework closely matches an ideal objective of JIT manufacturing presented by Miltenburg and Wijngaard (1991). They wrote:

> "the ideal implementation should consist of a sequence of steps. Each step should make a few small changes to the current production system, should be easy to implement, should cause no disruption to production, should require little capital expenditure, and should improve quality and reduce costs. The expertise acquired at each step should provide a foundation upon which the next step can be built."

Chapter Seven

Conclusions

7.0 Introduction

This chapter presents the conclusions of the thesis. They are set against the research objectives and the five key research propositions identified in the first chapter. Issues for further research are identified.

7.1 Conclusions

Analysis of the scope of JIT manufacturing found that:

- JIT manufacturing is based on the elimination waste;
- support levers, which are not directly the source of performance improvement, provide knowledge and encouragement for techniques for the elimination of waste. Fourteen support levers were identified (Table 2.5);
- of the many waste elimination techniques of JIT manufacturing, a core set of thirteen were identified from surveys which typify current practice of JIT manufacturing (Table 2.6); and,
- performance measures guide and monitor the process of JIT implementation. Twenty three performance measures of relevance to practitioners were identified from literature (Table 2.7).

Examination of approaches to the implementation of JIT manufacturing showed that:

- a wide range of issues have been perceived to affect the implementation of

JIT manufacturing. Relationships between these have not been clearly established in the past. There is no agreement regarding the relative significance of each implementation issue and none have been shown to be dominant in all cases;

- researchers acknowledge that JIT manufacturing must be implemented gradually over a long period of time. This raises the problem of how to determine which elements of JIT manufacturing should be applied, where in the manufacturing system, and when. This was referred to by the researcher as the JIT implementation dilemma;
- a small number of JIT implementation structures were presented as early contributions to guide the process of JIT implementation. These did not provide detailed guidance or a solution to the JIT implementation dilemma;
- many prescriptive frameworks and guidelines for JIT implementation have been proposed. These present a risk of failure as they forecast the presence and significance of implementation issues which may be incorrect; and,
- tailored frameworks have been presented. In theory, these overcome the risk of failure of prescriptive frameworks. In practice, present tailored frameworks do not present a solution to the JIT implementation dilemma.

Conclusions against the key research propositions identified in the research design are as follows:

- *"establish if there is one prescriptive framework to successfully guide the process of implementing JIT manufacturing."*

  There is not one prescriptive framework to successfully guide the process of JIT implementation. The three case studies demonstrated that a prescriptive framework would not have been able to guide the process of JIT implementation. Consensus across the cases was not achieved regarding the implementation of any of the waste elimination techniques which typify current practice. This is supported by further researchers who identify successful multiple cases of JIT implementation where each case pursued a different approach.

- *"establish if there is one prescriptive framework to successfully guide the process of implementing JIT manufacturing for an industrial sector, such as the commercial aircraft manufacturing industry."*

  There is not one prescriptive framework to successfully guide the process of implementing JIT manufacturing in an industrial sector, such as the commercial aircraft manufacturing industry. A conclusion the author has reached, together with other researchers, is that industry type does not determine the process of JIT implementation. The three cases did not demonstrate consensus regarding how to proceed with implementation, despite all being in the same industry, and this was supported by cases presented by others.

- *"establish if each company should pursue a level of JIT implementation selectively, adopting JIT practices based on its particular circumstances."*

  Each company should not pursue a level of JIT implementation selectively, adopting JIT practices based on its particular circumstances. The manufacturing system is the important unit of analysis, not the company. Within a company, cases must approach JIT implementation differently. This was demonstrated by the cases, where three cases within one company followed different paths to JIT implementation. This was supported by cases presented by the researcher and others. Manufacturing systems that span companies should be ultimately considered as one manufacturing system, and again it is not the company that is the important unit of analysis.

- *"establish which issues affect the implementation of JIT manufacturing."*

  Two variables were identified from this research. These determined whether or not thirteen waste elimination techniques were applied in three cases. This was supported by consideration of other cases presented in literature. These variables were the perceived opportunity for improvement and the measure of distributed support.

- *"establish how implementation issues can combine to influence the implementation of JIT manufacturing."*

  Waste elimination techniques with a high perceived opportunity for improvement and strong measure of distributed support can be successfully implemented. A low perceived opportunity for improvement or weak measure of distributed support means that implementation must be postponed due to unacceptable risk of failure. Where the perceived opportunity for improvement is high and the measure of distributed support is low, implementation of the relevant waste elimination technique must be delayed until the measure of distributed support is increased through the use of support levers. Where perceived opportunity for improvement is low, implementation is a low priority.

The researcher concludes that a novel framework has been developed that supports practitioners throughout the implementation of JIT manufacturing in the commercial aircraft manufacturing industry. The framework presents a systematic and practical method that reliably enables practitioners to identify an implementation plan for JIT manufacturing that is suited to the particular circumstance of the manufacturing system.

Validity has been strongly established in discrete batch machining environments, due to the nature of the test domain of the cases and the majority of the literature based cases. Although the principles developed may be applicable in other areas, validity has not been fully established in other environments, notably assembly. This represents a subject for further research.

The framework is most relevant for the early stages of JIT implementation, having been validated by three case studies during the first five months of implementation. The author recognises the likelihood of the process changing, and this is identified in the discussion of the framework as desirable. An objective of further research is the refinement of the framework as cases progress towards the mature stages of JIT implementation. This could result in the identification of a threshold, past which other mechanisms could be used to guide the implementation of JIT manufacturing.

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Appendix A

Practical Process For Strategy Identification

A.0 Introduction

A set of worksheets discuss the steps of: understanding market position; assessing the manufacturing operation; and developing a new strategy. The later steps are generally wider in scope than the subject of JIT manufacturing and its implementation, and hence beyond the domain of this thesis. However, the first step specifies a number of exercises which consider external perspectives of the manufacturing system to identify the strategic objectives of the manufacturing system. It identifies on which criteria the manufacturing system qualifies for, and then wins orders for each of its product groups. The current performance of the manufacturing system in the qualifying and winning criteria is evaluated, and gaps between desired and achieved results highlighted. This provides understanding of the competitive advantage sought by the company, and highlights the criteria in which the manufacturing system should seek to improve performance. A conceptual example is discussed throughout (Platts and Gregory 1988: 13-38).

The process of the strategy identification stage, Figure A.1, uses Tables A.1, A.3, and A.4.

It can start with the basic product family market data which is collected in the format shown, Table A.1. Each product family is assigned to a row in the left hand column. The percentage of all sales realised by the family is given in the second column. The percentage of the total contribution made by the family is given in the third column. The market share, otherwise market share ranking, for the product family is given in the fourth column, along with information for competitors if this is known.

Growth and market growth columns are completed as follows: -2 declining rapidly; -1 declining; 0 static; +1 growing; and +2 growing rapidly. Lifecycle stage is specified as market entry, rapid growth, maturity, or decline, Table A.2. This analysis, and particularly the right hand column, indicates which product families are important in the future success of the company.

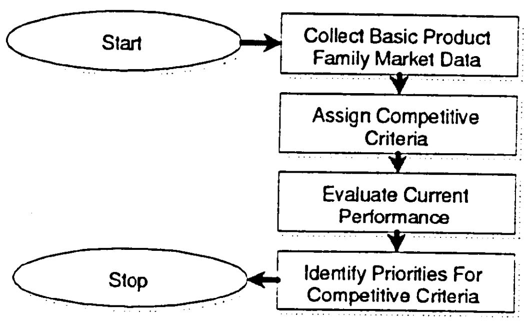

Figure A.1: Strategy identification process (based on Platts and Gregory 1988)

Basic Product Family Market Data

Product Family	Sales as % of total	Contribution as % of total	Market share/ranking; number of competitors	Growth (-2 to +2)	Market growth (-2 to +2) /lifecycle stage
1					
2					
etc.					

Table A.1: Basic product family market data (Platts, and Gregory, 1988: 20)

The competitive criteria for each product family are assigned in the format shown, Table A.3. Product families are listed in the right hand column, as in Table A.1. A "Q" is entered to indicate where a criterion is required for qualification into the market for a product family, and one hundred points are assigned across the seven criteria according to their relative importance in winning orders. This highlights for each product family the key competitive criteria which require high levels of performance in order to secure future orders.

Current manufacturing performance, in terms of the strategic competitive criteria, is collated in the format, Table A.4. Again, product families are listed in the right hand column, as in Table A.1. For all product families and each of the competitive criteria an assessment of current performance is made as follows: -2 where the company competes at a strong disadvantage to competitors; -1 where the company competes at a disadvantage; 0 where competition is neutral; +1 where the company enjoys a competitive advantage over competitors; and +2 where the company enjoys a strong competitive advantage over competitors.

Lifecycle Stage	
Market Entry	The product is produced in low volume and the design is probably under review. Requires flexibility of the manufacturing system, with general purpose equipment and skilled or multi-skilled people. The product probably sells on design features and is relatively insensitive to price, delivery, etc.
Rapid Growth	Design becomes established. Competition and volume increase. Price competition puts pressure on costs, leading to standardisation of design and processes. Tasks become structured and automation may be introduced.
Maturity	The product generally competes more and more on price. Volumes are high. Automation and special purpose equipment may be appropriate. Operators may be less skilled, but support services can be highly technically skilled.
Decline	Price competition becomes severe in early decline. Volumes decrease and automated plant becomes less efficient. Flexibility and general purpose equipment become more effective. In late decline, price may not be as important as availability for spares, etc.

Table A.2: Lifecycle stages (Platts and Gregory 1988: 13-14)

Competitive Criteria

Product family	Features	Quality	Delivery leadtime	Delivery reliability	Design flexibility	Volume flexibility	Price
1							
2							
etc.							

Table A.3: Competitive criteria (Platts, and Gregory, 1988: 26)

Current Strategic Manufacturing Performance

Product family	Features	Quality	Delivery leadtime	Delivery reliability	Design flexibility	Volume flexibility	Price
1							
2							
etc.							

Table A.4: Current strategic manufacturing performance (Platts, and Gregory, 1988: 38)

The tables are circulated to the planning group members by the planning group leader who assigns responsibility across members for the collection of the appropriate information. Once the information is collected and collated, the planning group meet to discuss and review the worksheets and determine the priorities for the competitive criteria for all product families. This is based on comparison of current strategic manufacturing performance for the important product families, Table A.4, with the key competitive criteria, identified in Table A.3. The competitive criteria that require most urgent improvement for each product family are those with the greatest importance in Table A.3, and in which the company competes at a disadvantage or strong disadvantage, in Table A.4. This identifies which competitive criteria require most urgent improvement for each product family. A clear statement of the relative priorities of the competitive criteria for each of the product families is then made by the planning group.

Appendix B

Practical Process For Performance Measure Selection

B.0 Introduction

A process for the selection of performance measures to support the identified strategy is given in Figure B.1. This is developed from exercises presented by Lynch, and Cross (1991: 127-129).

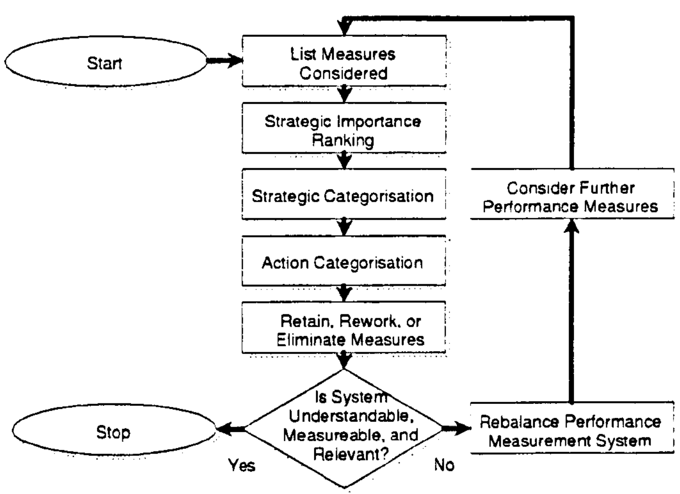

Figure B.1: Performance measure selection (based on Lynch and Cross 1991: 127-129)

The first step is to list all measures that are used in relation to the area of the manufacturing system in which JIT implementation is being pursued, and describe their use in operations. During this step, Eccles (1991) identifies the need to develop a grammar and vocabulary to define performance measures and their evaluation. This may involve planning group members from different functions such as accounting, design, maintenance, and operations. The next step is for the planning group to rank the measures according to their importance to the identified strategy, as follows: A, very important; B, somewhat important; and C, inappropriate. The measures are then categorised into the seven strategic competitive criteria considered in the strategy identification step, Table 7.1. This demonstrates how relevant the performance measures are to the identified strategy, and clearly highlights the implicit message communicated by the existing performance measurement system. The measures are then further categorised into one of six action categories, Table B.1, and the appropriate actions of retaining, reworking, and eliminating are decided. Those measures that are retained and reworked are evaluated to determine whether the group of selected measures are: widely understandable by people in the manufacturing system whose performance is being appraised (Wheelwright, and Clark, 1988: 141); measurable in practical terms; and relevant to and reflect priorities in the competitive criteria in the identified strategy (Globerson, 1985). If the selected measures do not meet all of these objectives then the performance measurement system is modified by the further consideration of additional performance measures, such as those from the pyramidal model, Tables 3.4, and 3.5.

Category	Action
Measures that track strategy achievement	These are especially effective and remain in place
Measures that support actions to achieve strategy	Should be given added visibility and attention
Measures not aligned with business strategy	Rework the measure or where and when reported
Measures that are irrelevant to strategy	Consideration should be given to elimination
Measures that delay or defeat strategic achievement	Should be eliminated immediately
Hidden cultural measures that defeat strategy	Bring to the surface and replace explicitly

Table B.1: Performance measure selection action categories

When the planning group reach consensus that the selected measures meet the objectives of being understandable, measurable, and relevant, the measures are listed and their use in operations defined according to the agreed grammar.

Appendix C

Framework Documents

Opportunity Evaluation Worksheet

Instructions:

For the manufacturing system area shown, please allocate scores to each of the waste elimination techniques given in proportion to its ability to contribute towards the stated long and short term objectives. The accumulation of the scores shall not exceed three times the number of waste elimination techniques given. Notes may be given to highlight points of importance in the allocation of scores. Please do not consult other planning group members, or others.

Manufacturing System Area:

Long Term Objectives	Short Term Objectives
1:	1:
2:	2:
3:	3:
4:	4:
5:	5:

Waste Elimination Technique	Opportunity	Accumulation	Notes
1:			
2:			
3:			
4:			
5:			
6:			
7:			
8:			
9:			
10:			
11:			
12:			
13:			

Support Evaluation Interview Form

Local/Factory Service/Supply Chain Area:

Manufacturing System Area:

Waste Elimination Technique	Support (0-9)	Reasons For Support Being Offered / Withheld
1:		
2:		
3:		
4:		
5:		
6:		
7:		
8:		
9:		
10:		
11:		
12:		
13:		

Guidance For The Application Of Waste Elimination Techniques

Source	Flexible/cross trained workforce	WIP reduction and small lot sizing	Partnership sourcing/JIT purchasing	Total Productive/ Preventive maintenance	Setup reduction
Schonberger (1982)			pp157-169	pp68-69 pp136-138	pp1-2 pp20-22
Schonberger (1986)			pp133-135 pp155-169	pp67-72	pp109-111
Dyer (ed) (1987)	pp103-116	pp129-130			
Suzaki (1987)					
Ohno (1988a)	pp10-11			pp63-65	
Shingo (1989)	pp57-60 pp156-161			pp119-121	pp43-57 pp106-114
Monden (1994)	pp159-175		pp75-88		pp9-10 pp121-144
Others	Schonberger (1990) 125-141 Suzaki (1993) pp116 pp367-374		Hall (1982) Hay (1988) pp117-150 O'Grady (1988) pp103-113	Nakajima (1988) Nakajima (1989) Shirose (1992) Shirose (1993)	Shingo (1985) pp21-333 Hay (1988) pp53-69 O'Grady (1988) pp80-82 Sekine and Arai (1992)

Guidance For The Application Of Waste Elimination Techniques

Source	Product simplification, standardisat'n modularisat'n	Quality at source	Smoothed/ levelled and mixed production	Layout improvement	Visual control
Schonberger (1982)		pp25-27 pp47-82 pp181-198	pp18-20 pp93-94 pp143-151	pp104-123 pp141-142	pp56-59 pp91-92
Schonberger (1986)	pp144-154	pp123-133 pp135-143 pp201-203		pp5-7 pp77-86 pp101-122	pp17-26 pp172-174
Dyer (1987)					
Suzaki (1987)					
Ohno (1988a)			pp12-13 pp36-40 p126	pp10-11 pp33-35	p21 p121 pp128-129
Shingo (1989)		pp8-21 pp117-119	pp123-136	pp102-103	
Monden (1994)			pp8-9 pp63-74 pp253-278	pp10-11 pp159-176	
Others	Hutchins (1988) pp67-96 Schonberger (1990) pp212-236	Hay (1988) pp137-150 O'Grady (1988) p39 Schonberger (1990) pp65-88 McTighe (1992) p6	Hay (1988) pp33-51 Burbidge (1989)	Hay (1988) pp71-88 Burbidge (1989) pp1-146	Schonberger (1990) pp96-111 Greif (1991) Suzaki (1993) pp410-416

Guidance For The Application Of Waste Elimination Techniques

Source	Housekeeping 4S/5S/6S/ workplace organisation	Autonomation / Autonomous defect control	Pull control/ kanban
Schonberger (1982)	pp66-68		pp219-238
Schonberger (1986)	pp26-31	pp75-76	
Dyer (ed) (1987)			
Ohno (1988a)		pp6-7 pp121-122	pp25-42
Shingo (1989)		pp21-25 pp57-60 pp136-138 pp161-164	
Monden (1994)	pp199-220	p5 p12 pp221-238	
Others	Ohno (1988b) pp116-120 Kobayashi (1990) Harrison (1992) pp115-117	Nikkan Kogyo Shimbun Ltd. (1989)	Schonberger (1990) pp112 McTighe (1992) Esparrago (1988)

Appendix D

Case Details and Analysis

D.0 Introduction

This appendix presents further detailed information from the three cases. Discussion of the approach to the research method that is common to all cases is covered first, followed by detailed analysis of each stage of the research. Points of interest from each of the three cases are identified throughout.

D.1 Research Method

According to McTaggart (1982) action research involves plan, act, observe, and reflect stages.

- The plan stage looks to the future and hence is prospective by definition. The general plan must be flexible enough to adapt to unforeseen effects and previously unrecognised constraints.
- Action looks back to planning for its rationale. But action is not completely controlled by plans. It takes place in real time and encounters real political and material constraints (some of which arise suddenly and unpredictably as a consequence of the setting).
- Observation is necessary because action will always be limited by constraints of reality, all of which will not be clear in advance. Observation must be planned, so that there will be a documentary basis for subsequent reflection. However, like the action itself, observation plans must be flexible and open to record the unexpected. There is a need to observe the action process, the effects of action, the circumstances of and constraints on action, the way circumstances and constraints limit or channel the planned action and its effects, and other issues which arise.
- Reflection recalls action as it has been recorded in observation. Reflection provides the basis for the revised plan. Reflection allows more complete understanding of the situation, constraints on action and what might now be possible. Reflection can be supplemented through reviews with people involved in the plan and action stages.

McTaggart (1982) identified techniques for monitoring action research, the following of which were employed in this research:

- anecdotal records/field notes which provide written descriptive accounts of events (eg meetings, training sessions, etc) including the context and events relevant to the issue under investigation;
- diary/log which records observations, feelings, reactions, interpretations, reflections, hunches, hypotheses, and explanations organised with respect to time allocations;
- portfolio or collection of materials, such as minutes of meetings and newspaper cuttings. In short, any documents or accounts of interest and relevance to the issue in question. This included training material used and copies of the recommendations of the senior KHI engineers;
- document analysis which presents a picture constructed from a variety of documents, such as memoranda to staff, noticeboards, annual reports, letters, and procedures;
- interviews, mainly unplanned and unstructured. These included the General Manager, Production and Quality Directors, four production managers, over thirty production people (including supervisors, skilled and semi-skilled operators, and engineers), maintenance staff, engineering, finance, and systems specialists. In addition to this, interviews were also conducted with people from four other British Aerospace factories (Chester, Filton, Lostock, and Prestwick) and Kawasaki Heavy Industries;
- video recording, mainly of shopfloor activities;
- photographs which are useful to support other forms of recording and monitoring.

D.2 Planning Phase

The senior KHI engineers presented their recommendations for the pilot applications of KPS within British Aerospace Chadderton to the Production Director affected, four production managers, one engineering manager, and the researcher. The three cases were identified as the pilot areas, with the objectives of 30% reductions in work in progress and inventory, and a 30% increase in productivity. The Production Director accepted these recommendations and instructed each of the three cases to present a project plan shortly after the return of the engineers from the KPS training course in Japan. This was in response to the desire of the Chadderton Board to be kept informed of the activities regarding the implementation of KPS. The main mechanism for this was the project plan.

For each case, project plans were developed by the production manager, supervisor, and engineer in a planning meeting. At the beginning of the implementation, the engineer had received far more training in the methods of JIT manufacturing than the production manager and supervisor. The format of the planning meeting followed presentation of recommendations by the engineer, leading to discussion and evaluation of these by the production manager and supervisor.

The main consideration of the planning meeting was to identify which of the many potential actions would generate the greatest progress towards the objectives of 30% improvement set by the senior KHI engineers. Each planning group was aware of the degree of importance attached to the implementation of JIT manufacturing by the Chadderton Board and the high level of support that the programme would attract. Support, or the lack of support, for the implementation activities was not fully considered in the initial project plans for this reason. The planning horizon of the project plans for the cases ranged from eight to seventeen weeks. The opportunity for improvement was different for each waste elimination technique in each case. Each case presented a different project plan because of this. The details of the opportunity for improvement were discussed in detail in chapter four.

The three plans were presented to the Chadderton Board. All plans were "completely accepted" by the General Manager. With regard to access to facilities and support services, the General Manager stated that "nothing is a problem".

D.3 Action Phase

Implementation closely followed the plans generated in the planning stage that were accepted by the Chadderton Board. The actions for each case were discussed in chapter four, and summarised in Table 4.1. Despite the acceptance of the plans by the Chadderton Board, there were some instances where actions deviated from the plan. These included:

- single-skilling presented difficulties in making people available to attend training courses and improvement exercises. This affected all three cases and constrained the rate of improvement towards and beyond the objectives that was achieved;
- formal procedures for access to budgets slowed progress on many small improvements identified from the improvement exercises. This affected all three cases. The nature of the many of the actions required large numbers of small developments to the manufacturing system and formal procedures presented a significant barrier to JIT implementation;
- financial year-end pressures for deliveries heavily disrupted the availability of managers, supervisors, engineers, operators, and support services for the purposes of JIT implementation. This affected all three cases;
- alternative programmes developed by others within Chadderton deprived the JIT implementation activities of resources according to the preferences of the suppliers of the support towards the sponsors of the alternative programmes. This affected all three cases;
- the blocking of some improvements towards JIT manufacturing by some suppliers. This primarily affected the titanium undercarriage assembly case

with the suppliers of expensive titanium alloy forgings from the USA, France, and the UK. Traditionally, large batches of forgings representing several months of production would be supplied, resulting in very high levels of raw material stocks. Whilst some suppliers modified the pattern of their deliveries, other suppliers strongly resisted smaller and more frequent deliveries. This reduced the progress towards the objectives;

- customers blocked some improvements in JIT implementation. This affected improvement of layout in the case of the buttstraps due to an unacceptably high risk that customer deliveries would be disturbed. Further demands included the retention of an internal schedule for the delivery of products which incorporated a safety time buffer which affected all three cases. These decisions reduced the rate of progress in JIT implementation;
- engineering support services delayed the introduction of batch size reduction in the case of the rib assemblies. Historically, a manufacturing batch size of three had been used on the long bed three-spindled NC mill, using all spindles. The delivery of rib assemblies was constrained by the machining of billets on the long bed mill. The proposal of using only one spindle was not easily accepted by engineering. Once introduced, setup times were greatly reduced and production output using one spindle exceeded that achieved using three.

Frequent reviews of progress were held by different people throughout the action phase. The production manager, supervisor and engineer informally reviewed progress on most days, holding a meeting each fortnight. The General Manager informally reviewed progress on most weeks, often visiting the pilot areas with visitors to the site. The Production Director followed a similar pattern of reviewing progress, and also instructed the production manager to provide a progress report on a monthly basis. Finally, the combined Boards of British Aerospace Plc and Kawasaki Heavy Industries visited the pilot areas several months into the implementation.

D.4 Observation Phase

During early stages of implementation it was not clear what information was important. To counter this, the monitoring of action activities was highly flexible in order to collect as much information as possible, and minimise the risk of not collecting information that would prove to be important. A highly valuable source of observations was the maintenance of a daily research diary. This directed the collection of information.

The results according to the identified objectives of work in progress reduction, leadtime reduction, and increased productivity, together with the further performance measures of setup reduction and batch size reduction were presented in Table 4.2. These generally exceeded the objectives set by the senior KHI engineers.

D.5 Reflection Phase

The perceived opportunity for improvement in the selection of implementation activities and providing a solution to the JIT implementation dilemma was shown to be important in achieving and generally exceeding the objectives set by the senior KHI engineers.

Top management commitment was clearly extended to all three JIT implementation plans. However, this did not clearly explain all of the events observed during the action phase. From analysis of these events, the concept of distributed support was identified. The elements of the concept of distributed support included:

- local production areas. This was a combination of the production manager, supervisor, engineer, and operators. This was considered implicitly throughout the planning and replanning process. Although operators were not involved in the planning meeting itself, all those present were highly aware of the need to consider the views and took steps to ensure that this was done. These often included presenting and checking the proposed plan with a group of operators;
- factory service functions. One example identified was the blocking by engineering of the proposed batch size reduction for a period of time. Other service functions whose support was important included maintenance, finance, and personnel;
- supply chain. This extended in both directions towards customers and suppliers. Customers affected all three cases by demanding the retention of an internal delivery schedule, and impacted upon the buttstrap case by withholding support and thereby preventing the improvement of the layout. Suppliers affected the titanium undercarriage assembly case by preventing the further use of more frequent deliveries of smaller batches.

The support from people generally increased dramatically several months into the implementation as it became apparent that considerably greater improvement was occurring than under previous change efforts. This was strongest among local operators who were in a position to see their own ideas being supported and implemented.

Developing support in areas was identified as a realistic course of action. Subsequently, resources were directed at improving support, mainly by increasing awareness through presentations and hosting visits to the cases in Chadderton.

Support levers were also identified from the reflection phase. These included the establishing of local budgets for small low cost improvement ideas, and training. A further list of the fourteen support levers identified from the cases and literature is given in Table 2.5.

The combination of the two factors of the concepts of the level of perceived opportunity for improvement and the measure of distributed support resulted in four permutations, the significance of which are explained in chapter five.